Effects of diet formulation on pellet mill performance and pellet quality on grow-finish pig growth performance

by

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Abstract

A total of 4 experiments were conducted to determine the effects of diet formulation on pellet mill production parameters, subsequent pellet qualities and the effects of pellet die thickness and pellet quality on grow-finish pig growth performance. Pellet mill production rates can directly affect pelleting costs due to diet costs being able to be divided by a larger denominator of feed produced. However, it has been generally accepted that increasing pellet mill production rates has a negative effect on pellet quality. Therefore, the first two experiments were conducted to evaluate the impact of pellet mill electrical consumption, pellet mill production rates, and subsequent pellet qualities. Exp. 1 was conducted at a commercial feed mill and set as a 2 × 2 × 2 factorial with main effects of diet formulation (0 or 30% DDGS inclusion), Azomite® (AZO; Azomite Feed Grit, Nephi, UT) inclusion (0 or 0.25%), and pellet mills (1 or 2; both mills were 500-horsepower, Andritz, Model 32-700, Esbjerg, Denmark). There were a total of 4 replications per treatment per pellet mill. Pellet mills were equipped with either 4.4 × 39.0 mm (L:D 8.9) or 4.4 × 35.8 mm (L:D 8.2) and production rates were held constant at 31.75 MT per hour. Conditioning temperature was held constant at 82°C. Treatment replications consisted of 43.54 MT with a 43.54 MT "flush" pelleted after any treatment containing AZO to recoat the pellet mill die with feed particles. Exp. 1 resulted in a DDGS × PM interaction (P = 0.040) with the inclusion of DDGS increased pellet mill kWh/MT in PM 2 while electrical consumption was decreased by DDGS inclusion in PM 1. For kWh/MT standard deviation (STD), an AZO × DDGS (P = 0.026) interaction was observed in that there were no differences in kWh/MT STD for 0% DDGS whereas AZO inclusion reduced kWh/MT STD for diets containing 30% DDGS. PDI was reduced (P < 0.05) by AZO inclusion in the diet. However, the inclusion of 30% DDGS improved (P < 0.05) PDI compared to treatments without DDGS.

Exp. 2 was conducted at the O.H. Kruse Feed Technology and Innovation Center at Kansas State University (Manhattan, KS). Exp. 2 was designed as a 2 × 2 factorial in a 4 × 4 Latin Square design with main effects of diet formulation (0 or 30% DDGS) and AZO inclusion (0 or 0.25%) to evaluate the impact of pellet mill production rates (California Pellet Mill, 3016-4) and subsequent pellet quality. Treatments were replicated 4 times over 4 separate days. Treatment replications consisted of 2.72 MT with pellet mill motor load held constant at 70% by

adjusting the pellet mill feeder VFD. For Exp. 2, the inclusion of AZO to the diet increased ($P <$ 0.05) pellet mill production rates. Whereas the inclusion of 30% DDGS reduced ($P < 0.05$) pellet mill production rate. There was a tendency for an AZO × DDGS interaction ($P = 0.0828$) with no differences in PDI's for treatments containing DDGS but the PDI's were reduced with the inclusion of AZO. In conclusion the addition of AZO reduces pellet mill electrical consumption and improves pellet mill production rate while reducing PDI's when conditioning temperatures remain constant.

Exp. 3 was conducted to determine the effects of pellet quality on pig growth performances over three distinct weight ranges. A total of 350 pigs (line 600 × 241; DNA) were fed over three weights ranges. Pigs were weighed before each weight range with pens randomized to treatment for each weight range. There were 35 total pens with 10 pigs per pen and 7 replications per treatment. Pigs were fed experimental treatments for 20, 21, and 20 days for weight range 1, 2, and 3, respectively. Treatments consisted of a mash control and pellets with fines included at 9-16, 41-47, 60-68, and 84-91%. A 10-day washout period was used between each weight range where a common diet was fed to alleviate residual carryover of pelleted treatments. For weight range 1, 44-68 kg, pigs fed pellets with 13% fines had increased ($P < 0.05$) G:F compared to pigs fed the mash. Pigs fed pellets had increased (linear, $P = 0.006$) ADFI as pellet fines increased at the feeder. Whereas pig G:F decreased (linear, $P = 0.002$) as percent fines at the feeder increased. For weight range 2, 81-106 kg, pigs fed pellets with 16% fines at the feeder had improved ($P < 0.05$) G:F compared to pigs fed mash. Pigs fed 86% fines at the feeder had a tendency ($P < 0.10$) for increased ADFI compared to pigs fed mash, whereas pig G:F tended ($P < 0.10$) to decrease compared to pigs fed mash. Pig ADFI increased (linear, $P = 0.016$) as pellet fines percentage increased at the feeder. G:F improved (linear, $P = < 0.001$) as percent fines at the feeder decreased. For weight range 3, 118-144 kg, pigs fed pellets with fines inclusion up to 42% had increased ($P < 0.05$) G:F compared to pigs fed mash. Pigs fed pellets with 65% fines tended ($P < 0.10$) to have increased G:F when compared to pigs fed mash. Pigs fed pellets with 84% fines tended ($P < 0.10$) to have increased final BW and ADFI compared to pigs fed mash feed. Pig G:F increased (linear, $P = 0.005$) as the percentage of pellet fines decreased at the feeder. In conclusion, pigs fed pellets with minimal fines had the greatest improvement in growth responses with ADFI and G:F being negatively affected in a linear fashion as pellet fines increases at the feeder.

Experiment 4 was conducted to evaluate the effects of pellet die thickness and screening pellet fines prior to delivery of feed on pig growth performances. A total of 314 pigs (line 600 × 241; DNA, initially 52 kg) were fed treatments consisting of either mash, L:D 8.75 pellets, L:D 5.5 pellets fed as-is, L:D 5.5 screened pellets, and pellet fines for 76 days. Pigs were placed in 35 pens with 9 pigs per pen and 7 replications per treatment. Pelleted treatments resulted in 27.82, 42.10, and 36.90% fines at the feeder for L:D 8.75, L:D 5.5 as-is, and L:D 5.5 screened pellets, respectively. Pigs fed L:D 8.75 pellets had increased ($P < 0.05$) day 76 BW compared to pigs fed mash or L:D 5.5 pellets fed as-is. Pigs fed L:D 8.75 pellets had increased ($P < 0.05$) ADG compared to pigs fed mash, L:D 5.5 pellets fed as-is, or pellet fines. Pigs fed L:D 8.75 pellets had improved ($P < 0.05$) G:F compared to pigs fed mash or L:D 5.5 pellets fed as-is. Pigs fed L:D 8.75 tended ($P < 0.10$) to have increased HCW compared to pigs fed L:D 5.5 pellets as-is. In conclusion, increasing pellet die thickness improved pig growth performance, which is largely attributed to reduction to pellet fines present at the feeder.

Key words: pellet mill, distillers dried grains with solubles, electrical consumption, pellet quality, pellet fines

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Dedication

This thesis is dedicated to all my friends and family who have supported me through every venture that I have taken in life. I am blessed to be surrounded by so many people who care.

Chapter 1 - The effects of Azomite and distillers dried grains with solubles (DDGs) on pellet mill electrical efficiency, production rates, and subsequent pellet quality

ABSTRACT

Two experiments were conducted to evaluate the effect of Azomite (AZO) and 30% distillers dried grains with solubles (DDGS) on pellet mill electrical consumption (kWh/MT), production rate, and pellet quality. Exp. 1 was conducted as a 2 × 2 × 2 factorial with main effects of diet formulation (0 or 30% DDGS), pellet mill (1 or 2) and AZO (0 or 0.25%). Pellet mills were equipped with a 4.4 × 39.0 mm (L:D 8.9) or 4.4 × 35.8 mm (L:D 8.2) die with pellet mill production rates held constant at 31.75 metric ton (MT) MT/hour and conditioning temperature held constant at 82℃. A total of 4 replicates per treatment per pellet mill were used for Exp. 1. Exp. 2 was designed as a 2 × 2 factorial of treatments with 4 replicates per treatment to evaluate the impact of AZO and DDGS on pellet mill production rates (California Pellet Mill, 3016-4) and pellet quality. Pellet mill production rate was adjusted by the feeder screw to maintain 70% motor load and a 4.0 × 35 mm (L:D 8.75) pellet mill die was used. For Exp. 1, a DDGS × PM interaction (P = 0.040) was observed. Diets containing 30% DDGS had a decreased kWh/MT compared to the control when using PM 1, whereas no differences were observed for kWh/MT between 0 and 30% when using PM 2. A DDGS × PM interaction (P = 0.019) was observed for kWh/MT standard deviation (STD). Diets containing DDGS increased STD compared to the control when pelleted with PM 2; however, there was no evidence of difference between the DDGS and control diets when pelleted with PM 1. There was an AZO ×

DDGS interaction (P < 0.05) for kWh/ton STD. No differences were observed in kWh/ton STD when pelleting corn-soy diets with or without AZO while AZO reduced kWh/ton STD in 30% DDGS diets. Diets containing AZO had reduced (P < 0.05) kWh/MT and PDI compared to diets pelleted without AZO. Pellet durability index was improved (P < 0.05) for diets containing DDGS. For Exp. 2, diets containing AZO had increased (P < 0.05) pellet mill production rate compared to those without AZO. The inclusion of 30% DDGS reduced (P < 0.05) pellet mill production rate compared to the corn soy diet. There was a tendency for an AZO × DDGS interaction (P = 0.083) for PDI. Azomite inclusion to corn-soy diets reduced PDI while there was no evidence of difference in diets containing DDGS. In conclusion, the addition of 0.25% AZO to the diet improved pellet mill efficiency; however, this potentially leads to a reduced PDI depending on diet type and pellet mill settings.

INTRODUCTION

Increases in ingredient costs make it more advantageous to pellet feed due to improvements in growth performance, commonly attributed to increased gain to feed (G:F) (De Jong et al., 2016; Nemechek et al., 2016; Paulk and Hancock, 2016). However, deciding to pellet feed leads to constraints that can be created at the feed mill by reductions in feed production rates. Pellet mill production rate is influenced by conditioning temperatures, conditioner retention times, pellet die thickness and diet composition. For example, addition of DDGS in the diet has been shown to have negative effects on production rates at as little as 10% in the diet (Fahrenholz, 2008). Meanwhile, DDGS inclusions up to 30% have been used to negate increased ingredient costs.

To mitigate the negative effects of DDGS on pellet mill production rate, feed manufacturers could elect to include pelleting aids, but efficacies may vary depending on diet formulation. One such pelleting aid is Azomite (Azomite Mineral Products, Inc., Nephi, UT) (AZO), which is a *dacitic tuff breccia* and classified as a hydrated sodium calcium aluminosilicate (HSCAS). Hydrated sodium calcium aluminosilicates are considered anti-caking agents and could be used to reduce binding properties between particles, making it beneficial to add to diets with DDGS (United States Code of Federal Regulations, 21CFR582.2729). Previous research has suggested that the porous shape and anticaking properties reduce residual feed particles left on the inner surface of pellet mill dies, resulting in conditioned mash to be extruded easier through the die (Boltz et al., 2021, Tillman et al., 2020, and Jones et al., 2022). Previous research using AZO has been conducted on diet formulations with up to 16% of the total diet consisting of corn derived DDGS (Jones et al., 2022). However, no literature has been published to determine the effect of AZO on diets containing 30% DDGS to the diet. Therefore, the objective of these experiments were to evaluate pellet mill electrical consumption, production rate, and subsequent pellet durability index (PDI) when pelleting diets formulated with or without AZO and either 0% or 30% DDGS in the diet.

MATERIALS AND METHODS

Experiment 1

This experiment was arranged as a 2 × 2 × 2 factorial with main effects of DDGS (0 or 30% of the diet), AZO (0 or 0.25% of the diet), and 2 separate pellet mills. This experiment was conducted at the JBS Live Pork Hedrick feed mill (Hedrick, IA). Experimental diets were formulated to be isocaloric and formulated to meet the nutritional requirements for 43 to 71 kg pigs. For all replications, mixer added choice white grease was held constant at 1% of the total diet, as shown in Table 1. To determine pellet mill electrical consumption, pellet mill production rates and conditioning temperature were held constant. Therefore, two 500-horsepower pellet mills (Andritz, Model 32-700, Esbjerg, Denmark) were used to test our objective. Pellet mill (PM) 1 was equipped with a 4.37 × 38.86 mm die (L:D 8.9) while pellet mill 2 was equipped with a 4.37 × 35.81 mm die (L:D 8.2). Both pellet mills were controlled by the Repete Automation System (Sussex, WI). Pellet mill production rate was started at 27.2 metric ton (MT) per hour and 76.7℃. After achieving the production parameters, pellet mill production rate and conditioning temperature was increased to 31.8 MT per hour and 79.4℃, respectively. The conditioning temperature was then increased to 82℃ and production rate held constant at 31.8 MT per hour with a 1% variance dead band setting for the remainder of the replications. Treatment order was randomly assigned to pellet mills to be pelleted once per day by each mill. Treatment replications consisted of 43.5 MT. A 43.54 MT "flush" was pelleted after each AZO treatment to coat the pellet mill die and die holes with residual feed particles. Pellets resided in the counterflow cooler (Geelen Counterflow, Haelen, Netherlands) for approximately 10 min after being extruded through the pellet mill die. Therefore, pellet samples were collected approximately 10 min after pelleting parameters were achieved with subsequent pellet samples collected every 10 min after. Pellets were collected from a port in the bottom of the discharge drag below the cooler for pellet durability index (PDI) analysis as described below.

Pellet mill electrical data was collected by a Dent power recorder (Dent Instruments ELITEpro XC™, Bend, OR). Electrical data collection was recorded in amps with data point collection occurring every 15 s during pelleting. Due to pellet mill roll slippages during the pellet mill runs, 25 min of pellet mill run time was evaluated for pellet mill electrical usage and efficiency. This resulted in 100 data points analyzed per pellet mill treatment replication. The following equations were used to determine the electrical consumption and standard deviation (STD) of electrical consumption which was derived from Stark (1994):

$$kWh\ per\ MT = \frac{\sqrt{3} \times Amps\ \times\ Voltage\ \times\ Power\ Factor}{(MT\ per\ hour\ \ \times\ 1000)}$$

$$STD\ of\ kWh\ per\ MT = \frac{\sqrt{3} \times STD.of\ Amps\ \ of\ \times\ Voltage\ \times\ Power\ Factor}{(MT\ per\ hour\ \ \times\ 1000)}$$

For the purposes of this experiment, voltage, power factor, and MT per hour were held constant at 480, 0.87, and 31.8, respectively.

Experiment 2

Experiment 2 was completed at the O.H. Kruse Feed Technology and Innovation Center at Kansas State University (Manhattan, KS) to determine the impact of AZO and DDGS inclusions on pellet mill production rates and subsequent pellet quality. Treatments were arranged as a 2 × 2 factorial within a 4 × 4 Latin Square with 4 replicates per treatment. The diets formulated were similar to that of the first experiment with mixer added fat, soybean oil, inclusion held constant at 1% of the total diet (Table 1). Treatments 1 and 2 contained 0 and 30% DDGS with 0.25% AZO added to the diet while treatments 3 and 4 contained 0 and 30% DDGS, respectively. All replications consisted of 2.72 MT and were mixed with a 907 kg dual ribbon mixer (Model MX-40, Hayes-Stolz Industrial Manufacturing Co., Burleson, TX). Treatment replications were steam conditioned for approximately 30 s (California Pellet Mill 18 INF 6.5) and subsequently pelleted with a 100-horsepower (California Pellet Mill, 3016-4) equipped with a 4.0 × 35 mm die (L:D 8.75). Pellet mill motor load was held constant at 70% with adjustments made to the pellet mill feeder screw to maintain 70% motor load. This allowed for the determination of dietary treatment effects on production rate.

Sample collection included mash, conditioned mash, hot pellet and conditioning temperatures, cooled pellets, and production rates. Mash, conditioned mash, and cooled pellets were used to analyze moisture content. Hot pellet samples were collected in a thermos with the maximum temperature achieved being recorded. Conditioning temperatures were observed from the control screen at the time of hot pellet sample collection. Pellet samples were collected from the chute opening on the front of the pellet mill and placed in an experimental counter flow cooler for 10 minutes. Three pellet mill production rates were collected by capturing pellets from the front discharge of the pellet mill for 10 seconds and then immediately weighed.

Pellet durability index

Pellet samples for both experiments were analyzed for PDI with a 30 s Holmen 100 test (TEKPRO, North Walsham, UK) via air agitation. Pellet samples were sieved using a Tyler #5 (4.0 mm) and #6 screen (3.4 mm) (W.S. Tyler, Mentor, OH) for experiments 1 and 2, respectively, and 100 g of sieved pellets were placed in the Holmen 100 chamber. After air agitation, remaining pellets were sieved once more with their respective sieves and weighed. Pellet durability index was then calculated by dividing the final screened pellet weight by the initial weight and multiplying by 100.

STATISTICAL ANALYSIS

Data were analyzed as a 2 × 2 × 2 factorial for Exp. 1 with main effects of AZO (0 or 0. 25% of the diet), DDGS (0 or 30% of the diet), and PM 1 or 2 and their interactions. For exp. 2, data were analyzed as a 2 x 2 factorial with main effects of AZO (0 or 0.25% of the diet) and DDGS (0 or 30% of the diet) and their interactions. Both experiments were analyzed using the PROC-GLIMMIX procedure of SAS 9.4 (SAS Institute, INC., Cary, NC). The fixed effect was the pelleting run with the day of pelleting serving as the random effect for both experiments.

RESULTS

Experiment 1

Pellet mill performance data were reported in Table 2. There was no evidence of a three-way interaction for AZO, DDGS, and PM for any of the analyzed response criteria. For kWh/MT, there was no evidence of interaction for AZO × DDGS or AZO × PM. An interaction was observed for DDGS × PM ($P = 0.04$) for kWh/MT. Diets containing 30% DDGS had a decreased kWh/MT compared to the control when using PM 1, whereas no differences were observed for kWh/MT between 0 and 30% when using PM 2. Pellet mill electrical standard deviation (STD) was analyzed for this study to further quantify the effects of AZO in common swine diets. A DDGS × PM interaction ($P = 0.019$) was observed for kWh/ton STD. Diets containing DDGS increased STD compared to the corn-soybean meal diets when pelleted with PM 2; however, there was no evidence of difference between the DDGS and corn-soybean meal diets when pelleted with PM 1. There was an AZO ×DDGS interaction ($P < 0.05$) for kWh/ton STD. No differences were observed in kWh/ton STD when pelleting corn-soybean meal diets with or without AZO while AZO reduced kWh/ton STD in 30% DDGS diets. Diets containing AZO had reduced ($P < 0.05$) kWh/MT and PDI compared to diets pelleted without AZO (Table 3). DDGS diets had improved PDI ($P < 0.05$) compared to corn-soy diets.

Experiment 2

Pellet mill motor load was held constant for all replications at 70% of rated capacity. The target conditioning temperature was 76.7℃ for all treatment replications. However, conditioning temperature achieved for 30% DDGS inclusion treatments were reduced to 64.5°C. Pellet mill conditioning temperatures were adjusted for diets containing 30% DDGS to allow for diets to be pelleted at a constant amperage without plugging. The conditioning temperatures resulted in hot pellet temperatures of 81.60℃ and 81.87℃ for control diets without AZO and with AZO, respectively. While treatments containing 30% DDGS resulted in hot pellet temperatures of

75.92℃ and 75.07℃ for diets without and with AZO inclusion (Table 3). There was no evidence of an AZO × DDGS interaction for pellet mill production rate (Table 3). Diets containing AZO had increased ($P < 0.05$) pellet mill production rate compared to diet pelleted without AZO. The inclusion of 30% DDGS reduced ($P < 0.05$) pellet mill production rate compared to diets pelleted without DDGS. An AZO × DDGS interaction (P = 0.0232) was observed for kWh/MT. The addition of AZO to corn-soybean meal diets reduced electrical consumption required to pellet 1 MT while the same degree of reduction was not observed in the 30% DDGS diet. There was a tendency for an AZO × DDGS interaction ($P = 0.083$) for PDI. Azomite inclusion to corn-soybean meal diets reduced PDI while there was no evidence of difference in diets containing DDGS.

DISCUSSION

Components of the pelleting process, such as steam conditioning and feed retention time in the conditioner and die, expose feed to various degrees of heat, moisture, pressure, and sheer which changes the pellets' physical and chemical characteristics. When ingredients used in diet formulation are exposed to the steam conditioning process and extrusion through the die, the heat and moisture plasticize the soluble fractions of the diet and increase the agglomeration of dietary components (Lundblad et al., 2009). The interactions between these various components and their chemical composition influence the rate at which the feed moves through the die and ultimately affects pellet mill production rate. Previous research has demonstrated that DDGS may be included in up to 40% of the diet without negatively affecting pellet mill electrical consumption when diets are isocaloric (no mixer added fat for any treatments) and balanced to meet nutritional requirements of growing pigs (Fahrenholz, 2008). The author did not provide nutrient analysis of the DDGS used within the experiment. However, oil content within DDGS could reduce friction of feed as it passes through the die thus requiring less electrical consumption to be extruded. In the experiment conducted herein, inclusion of 30% DDGS reduced kWh/MT in one pellet mill while the same degree of reductions in electrical consumption was not observed within the second pellet mill. This illustrates that individual pellet mills (even the same models) can potentially react differently to diet formulation when under the same environmental conditions. The variation in the response to the data conducted herein compares to that of Fahrenholz (2008) and may also depend on differences in composition of DDGS.

Inconsistent electrical consumption throughout the duration of the pelleting run was observed with electrical consumption increasing and decreasing throughout the pelleting run. Therefore, the STD of pellet mill electrical consumption was calculated to understand the impact of DDGS and AZO on individual pellet mills and the consistency of the pelleting process. By calculating standard deviations, a better understanding of electrical consumption was observed between the two diet formulations. Pellet mill electrical STD is an estimate of the consistency of a pellet mill's operation. This demonstrates less electrical consumption from inadvertent electrical surges to the pellet mill which allows operators to control pellet mills more efficiently. In multiple pellet line facilities, increased electrical consumption STD between pellet mills requires operators to prioritize the pellet mill that has increased STD and reducing efficiency of other pellet mills within the facility by demanding more attention be paid to the pellet mill with increased STD. The inclusion of DDGS increased the STD of kWh/MT during pelleting in PM 2 while the same increase in STD of kWh/MT was not observed within PM1. However, the inclusion of AZO to treatments containing DDGS reduced the STD of kWh/MT while the same degree of reduction was not observed for the corn-soybean meal treatments. Within the current experiment, STD of electrical consumption was exacerbated by DDGS inclusion but the die scoring and polishing capabilities, proposed by Boltz et al. (2021), of AZO was able to negate the potential negative impacts of DDGS inclusion on electrical consumption consistency.

The inclusion of AZO reduced pellet mill electrical consumption by 3.27% and 6.66% for corn-soybean meal and 30% DDGS diets, respectively. These observations agree with previous research conducted by Bowen et al. (2022) that observed that the inclusion of AZO to the diet reduced pellet mill motor load by 1% when production rate was held constant for diets that were containing 5% DDGS. The difference in the degree of response to AZO could be explained by the difference in DDGS inclusions (30% vs 5%) rates within diets.

Pellet mill production rate is one of the largest key performance indicators for feed manufacturers, as this can be directly related to the cost of feed production. Due to logistical constraints at the manufacturing site in Exp. 1, the production rate experiment was conducted at the O.H. Kruse Feed Technology Innovation Center. It was observed that the addition of DDGS in the diet reduced pellet mill throughput by 15% and 17% without and with AZO, respectively. However, the addition of AZO improved pellet mill throughput by 8.31% and 5.19% for corn-soybean meal and 30% DDGS diets, respectively. These observations agree with Boltz et al. (2021) and Tillman et al. (2020) that AZO improves pellet mill throughput by 7% and 6% respectively. Whereas the inclusion of DDGS has been previously shown to decrease pellet mill production rate, which can be attributed to a reduction of feed bulk density as DDGS inclusion increases (Fahrenholz, 2008). Pellet mill throughput improvements with AZO could be due to the scrubbing and polishing factors that have been proposed. Boltz et al. (2021) suggested that the improvements to pellet mill production rates due to AZO inclusion is due to the coarse texture of AZO and scrubbing the pellet mill die of residual feed particles left in pellet die holes.

Removing feed particles from the die hole could create less drag for new feed particles to push through. Like the findings of the current study, Jones et al. (2022) observed that the inclusion of AZO to diets containing up to 16% DDGS had improved pellet mill throughput. However, the authors state the variability in pellet mill throughput between days could be a result of the variation in DDGS composition or treatment did not contain enough feed. It was hypothesized that the variation could also be due to the nature of AZO scrubbing the pellet die surface and with too small of treatment sizes (tonnage), not enough feed would be deposited back on the die for accurate assessments to be made pelleting DDGS with or without AZO.

Pellet durability index values are used as a predictive measure to quantitatively estimate pellet quality as opposed to categorical assessments based on visual estimations (Stark, 1994). Previous research has shown that addition of DDGS in the diet, reduced pellet durability index scores (Fahrenholz, 2008; Tillman et al., 2020). Contrary to the previous literature, PDI's were improved by the addition of 30% DDGS in the diets by 27 percentage points for diets without AZO when production rate was kept constant. Whereas PDI's were improved by 31 percentage points for diets containing DDGS and AZO compared to the corn-soybean meal diets with AZO. Feoli (2008) also observed improvements to PDI's for diets containing 30% corn DDGS; however, these findings of improvements to PDI for DDGS inclusive diets is minimal. Stark (1994) observed that increasing protein content of the diet improved PDI which could explain the observed improvements for diets containing DDGSS (19% CP) compared to corn-soybean meal diets (15% CP). Meanwhile, the inclusion of AZO to diets reduced PDI's by 8 percentage points and 4 percentage points for corn-soybean meal and 30% DDGS diets, respectively. These findings are in contrast with the observations by Tillman et al. (2020), who observed that the inclusion of AZO to the diet had no effect on PDI. To improve the pellet durability for the current experiments, increasing conditioning temperature for diets containing AZO could allow for increased heat and moisture penetration into the feed particles (Behnke, 1994). The improvements observed in PDI's in Exp. 1 and 2 for diets containing 30% DDGS is not commonly observed. Behnke (2007) attributed the reductions in PDI for DDGS-based diets to its reduced starch content and increased oil content.

Conclusions

In conclusion, pellet mill kWh/ton and standard deviation varies between mills when 30% corn DDGS are added to the diet. However, addition of AZO at 0.25% reduced pellet mill kWh/ton and its standard deviation. The inclusion of 30% DDGS to the diet reduced pellet mill production rates as expected but the inclusion of AZO to the diets improved pellet mill production rates by 8.3% and 5.2% for corn-soy and DDGS diets, respectively. The addition of 30% DDGS improved PDI for both experiments while the addition of AZO reduced PDI for both corn-soybean meal and 30% DDGS diet formulations; however, these improvements could be attributed to increased protein content of 30% DDGS diets.

Table 1.1. Ingredient Composition of experimental diets, as-fed basis[1]

Item	Corn-soybean meal	Corn-SBM-DDGS
Ingredient, %		
Corn	74.20	50.89
Corn DDGS	-	30.00
Soybean meal, Dehull, Sol Extr	21.00	13.10
Choice white grease[2]	1.00	2.50
Monocalcium phosphate	0.40	-
Calcium carbonate	1.25	1.35
Sodium chloride	0.55	0.40
Biolys liquid 32.5%	0.90	1.23
Methionine hydroxy analog	0.15	0.03
L-Thr	0.16	0.09
L-Trp	0.02	0.03
Vitamin trace mineral	0.15	0.15
Azomite[2]	+/-	+/-
TOTAL	100	100
Calculated analysis		
Standardized ileal digestible (SID) AA %		
Lys	0.98	0.98
Ile:Lys	57	61
Leu:Lysine	128	162
Methionine:Lys	34.3	30
Met & Cys:Lys	57	57
Thr:Lys	62	62
Trp:Lys	17	18
Val:Lys	65	73
His:Lys	39	42
Total Lysine, %	1.09	1.15
ME, kcal/kg	3,351	3,392
NE, kcal/kg	2,540	2,573
SID Lys:NE, g/Mcal		
CP, %	15.40	19.45
Ca, %	0.63	0.59
P, %	0.42	0.48
Available P, %	0.33	0.37

Table 1.2. Effects of Azomite[4] (AZO) and distillers dried grain with solubles (DDGS) addition on pellet mill electrical usage[1]

Item	Corn-soybean No Azo[4]	Corn-soybean AZO[4]	DDGS No AZO[4]	DDGS AZO[4]	SEM	Probability, *P*< Interaction[5]	AZO[4] × DDGS	AZO[4] × PM	DDGS × PM	AZO[4]	DDGS	Mill
kWh/MT[2]												
Pellet mill 1	7.72^{a}	7.55^{a,b}	7.48^{a,b}	6.77^{c}	0.158	0.226	0.255	0.598	0.040	0.003	0.027	0.850
Pellet mill 2	7.57^{a,b}	7.25^{b}	7.55^{a,b}	7.24^{b}								
Std. deviation[3]												
Pellet mill 1	0.08^{b,c}	0.07^{b,c}	0.14^{b}	0.06^{b,c}	0.025	0.670	0.026	0.621	0.019	0.014	0.002	0.349
Pellet mill 2	0.05^{c}	0.04^{c}	0.22^{a}	0.11^{b,c}								

[1]All treatments had 1% mixer added fat with the balance applied at via post pellet liquid application for 30% DDGS treatments.
[2]AZOMITE, Azomite Mineral Products, Nephi, UT.

[a-e]Means with differing superscripts are significantly different within row and column (*P* < 0.05).

[1]This experiment was set up as a 2 x 2 x 2 factorial with main effects of Azomite (0 or 0.25%), DDGS (0 or 30%), and pellet mill (1 and 2). Electrical data were collected in amps by the Dent power recorder (Dent Instruments, Bend, OR) with data points collected in 15 second intervals for the duration of the pelleting run. Data analyses were conducted on 25-minute pelleting runs at desired parameters of 82°C and 31.8 MT/hour. Pellet mill warm up was kept consistent throughout the experiment.

[2]kWh/MT= $\frac{(\sqrt{3} \times \text{Avg. Amps} \times \text{Voltage} \times \text{Power Factor})}{(1000 \times \text{MT per hour})}$

[3]Std. kWh/MT= $\frac{(\sqrt{3} \times \text{Standard deviation of Amps} \times \text{Voltage} \times \text{Power Factor})}{(1000 \times \text{MT per hour})}$

[4]Azomite, Azomite Mineral Products, Inc., Nephi, UT.

[5]Interactio n = AZO × DDGS × Mill.

Table 1.3. Effects of Azomite[3] (AZO) and distillers dried grains with solubles (DDGS) addition on pellet mill electrical usage and pellet durability index (PDI)[1]

	Corn-soy diet		DDGS			Probability, $P<$		
Item	No AZO[4]	AZO[4]	No AZO[4]	AZO[4]	SEM	AZO[4] × DDGS	AZO[4]	DDGS
kWh/MT[2]	7.65	7.40	7.51	7.01	0.117	0.274	0.004	0.032
Std. deviation[3]	0.06[b]	0.06[b]	0.18[a]	0.08[b]	0.019	0.033	0.019	0.002
Condition temperature,°C	82.09 ± 0.22	82.22 ± 0.27	82.34 ± 0.28	82.26 ± 0.33	-	-	-	-
Pellet durability index, %[5]	50.57	42.73	77.64	73.45	3.58	0.328	0.002	<0.001

[a-e]Means with differing superscripts within row denote an interaction and are significantly different ($P < 0.05$).

[1]This experiment was set up as a 2 x 2 x 2 factorial with main effects of Azomite (0 or 0.25%), DDGS (0 or 30%), and pellet mill (1 and 2). Electrical data were collected in amps by the Dent power recorder (Dent Instruments, Bend, OR) with data points collected in 15 second intervals for the duration of the pelleting run. Data analyses were conducted on 25-minute pelleting runs at desired parameters of 82°C and 31.8 MT/hour. Pellet mill warm up was kept consistent throughout the experiment.

[2]kWh/MT= $\frac{(\sqrt{3} \times \text{Avg. Amps} \times \text{Voltage} \times \text{Power Factor})}{(1000 \times \text{MT per hour})}$

Table 1.4. Effects of Azomite[4] (AZO) and distillers dried grains with solubles (DDGS) addition on pellet mill production rate and pellet durability index

	0% DDGS		30% DDGS			Probability, $P <$		
	0% AZO	0.25% AZO	0% AZO	0.25% AZO	SEM	AZO × DDGS	AZO	DDGS
Conditioning temperature, ℃	75.53	76.25	65.06	64.30	2.124	0.5111	0.9847	<0.0001
Hot pellet temperature, ℃	81.60	81.87	75.92	75.07	1.581	0.5568	0.7563	<0.0001
Production rate, MT/h[2]	3.61	3.91	3.08	3.24	0.103	0.2554	0.0006	<0.0001
kWh/MT	16.41[b]	15.57[c]	19.07[a]	18.92[a]	0.507	0.0232	0.0022	<0.0001
Pellet durability index, %[3]	83.16	73.42	86.19	84.23	2.642	0.0828	0.0112	0.0033
Moisture content, %								
Mash	12.00	11.97	12.35	12.34				
Conditioned mash	15.55	15.37	14.89	14.84				
Cooled pellet	12.03	12.00	12.00	12.01				

[a-d]Means within rows with different superscripts denote an interaction and are significantly different ($P < 0.05$).

[1]Production rate determined by collecting pellets from the front of the pellet mill for 10 seconds then weighing.

[2]Production rate determined using the formula (10 second production rate × 6) × 60.

[3]Pellet durability measured by the sieving 100 grams of pellets with a #6 sieve (W.S. Tyler, Mentor, OH) and air agitating for 30 seconds then sieving off remaining fines.

[4]Azomite, Azomite Mineral Products, Inc., Nephi, UT.

Chapter 2 - The effects of pellet quality and pellet die thickness on growth performance of finishing pigs

ABSTRACT

Two experiments were conducted to determine the effects of percentage pellet fines and pellet die thickness on finishing pig growth performance. In Exp. 1, 350 finishing pigs (600 × 241; DNA, Columbus, NE) were used over time across 3 separate weight ranges. In each of the three studies, there were 10 pigs per pen and 7 pens per treatment. The 3 weight ranges included 44 to 68 kg, 81 to 106 kg, and 118 to 144 kg. Treatments consisted of a mash control diet and pelleted diets with 9 to 16, 41 to 47, 60 to 68, and 84 to 91% fines measured at the feeder. From 44 to 68 kg, pigs fed 9 to 16% fines had improved ($P < 0.05$) G:F compared to those fed the mash diet. As percentage fines at the feeder increased, pig ADFI increased (linear, $P = 0.006$) while G:F decreased (linear, $P = 0.002$). For 81 to 106 kg, pig ADFI increased (linear, $P = 0.016$) as percentage fines at the feeder increased. Pigs fed pellets with 16% fines had improved ($P < 0.05$) G:F compared to pigs fed the mash control diet. Gain:feed ratio increased (linear, $P < 0.001$) as percentage fines at the feeder decreased. From 118 to 144 kg, ADFI increased (linear, $P = 0.006$) as percentage fines at the feeder increased. Pigs fed pellets up to 42% fines had improved ($P < 0.05$) G:F compared to pigs fed mash feed. As percentage fines at the feeder decreased, G:F increased (linear, $P = 0.002$). For Exp. 2, 314 pigs (600 × 241; DNA; initially 52 kg) were used in a 76-day study to evaluate the effects of pellet die thickness on pig growth performance and carcass characteristics. Treatments consisted of a mash control or pelleted diets from a thick die effective length:diameter ratio (L:D) (L:D 8.75) fed as-is, pellets from a thin die (L:D 5.5) fed as-is, screened thin die pellets (L:D 5.5), and pelleted fines fed as a meal. There

were 9 pigs per pen and 7 pens per treatment. Overall, pigs fed thick die pellets (L:D 8.75, 28% fines) had increased ($P < 0.05$) ADG compared to those fed either mash, thin die pellets (L:D 5.5, 42% fines), or pellet fines. Pigs fed L:D 8.75 pellets had increased ($P < 0.05$) G:F compared to pigs fed the mash treatment. In conclusion, minimizing the amount of pellet fines present at the feeder improved pig G:F. Increasing pellet die thickness reduced the amount of pellet fines at the feeder which also led to an improvement in growth performance compared to pigs fed mash diets, diets pelleted using the L:D 5.5, or pellet fines.

INTRODUCTION

Diet costs account for the largest financial input for pork producers during the grow-finish phases of production. To mitigate the increased financial input for these phases of pig production, producers may elect to pellet diets. Pelleting diets can improve bulk density of the diets, flowability, and pig growth performance. Feeding pigs pelleted diets increases G:F due to reduced feed wastage (Stark et al., 1994; Myers et al., 2013; Nemechek et al., 2015). Previous research has observed improvements of 5 and 8% for ADG and G:F, respectively, in pigs fed pelleted diets versus pigs fed meal diets (Paulk and Hancock, 2015).

When pelleting swine diets, producing good quality pellets is important to optimize the growth performance response to pelleting. Stark et al. (1994) observed that as pellet fines surpassed 30% at the feeder, growth performance benefits associated with feeding pellets decreased. Therefore, if adequate pellet quality is not achieved, pelleting may negatively affect profitability. Improving pellet quality is a multifaceted approach (Behnke, 1994) and typically leads to an increase in the cost of feed production. Pellet quality is influenced by conditioning temperature, diet formulation, and pellet die thickness. Increasing pellet die thickness, increases the shear force applied on the feed as it is extruded through the pellet die and higher compression increases binding capacity. This approach typically leads to a reduction in pellet mill production rate. Therefore, the goal to pelleting swine diets is to find the optimal balance between achieving pellet quality and maintaining necessary production rates. Limited data has been reported on the effects of pellet quality at different weight ranges within the grow-finish phase. Increasing pellet die thickness increases the residence time of feed in the die and allows for more bonding capabilities of pellets (Saensukjaroenphon, 2019). However, there has also been limited information on the impact of using various pellet die thicknesses or screening pellet fines on growth performance of pigs. Therefore, our objective for Exp. 1 was to determine if the response to pellet quality was dependent on the bodyweight range for grow-finish pigs. Subsequently, our objective in Exp. 2 was to determine the influence of pellet die thickness and removing pellet fines on growth performance of grow-finish pigs.

MATERIALS AND METHODS

The experimental procedures followed in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1: 43 to 68, 81 to 106, and 118 to 144 kg pigs

A total of 350 growing pigs (600 × 241; DNA, Columbus, NE, initially 43 kg) were used in a series of growth assays over the distinct weight ranges of 43 to 68, 81 to 106, and 118 to 144 kg for 20, 21, and 20 days, respectively. Pigs were housed with 10 pigs per pen and an equal number of barrows and gilts per pen. Pens measured 3.05 × 2.44 m, allowing 0.74 m^2 per pig. Pens contained one cup waterer and one two-hole dry self-feeder to allow for *ad libitum* access to feed and water. Pigs were fed a common diet until the onset of the first experimental weight range. At the initiation of each experimental weight range, pens were weighed and place into 1 of 7 blocks based on average pen weight. At which point, treatments were randomly allotted to pens for each weight range of pigs, resulting in 35 pens and 7 replicates per treatment. Between each experimental weight range, pigs were fed a common diet for 10 days consisting of a pellet and mash blend. Treatments were delivered to pens and recorded by the computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN). The Feedlogic system had two hoppers, for treatments consisting of pellets and pellet fines, the system loaded one hopper with pellet fines and the other with pellets. At feed delivery, pellet fines and pellets were blended at the feeder. Treatments consisted of the mash control, screened pellets, 75% pellets and 25% fines, 50% pellets and 50% fines, and 25% pellets and 75% fines.

Pigs were fed a diet with the same composition, but with different diet forms (Table 1). The diet was formulated to meet or exceed NRC (NRC, 2012) requirement estimates and manufactured in meal form (Hubbard Feeds; Beloit, KS) with a target particle size of 600-µm corn. The diet was then delivered to the O.H. Kruse Feed Technology and Innovation Center (Manhattan, KS) for further processing. The feed was subdivided to create the mash control and the remaining feed was pelleted to create the pellet and fines treatments. Feed was steam conditioned (twin staff pre-conditioner, Model 150, Wenger, Sabetha, KS) to a target of 82°C and pelleted using a 30-horsepower pellet mill (1012-2 HD Master Model, California Pellet Mill, Crawfordsville, IN). The pellet mill die used was 4.8 × 31.8 mm (L:D 6.67) for the 43 to 68 kg and 81 to 106 kg weight ranges (Table 2). Pellet mill production rate was determined by collecting pellets for 30 s from the front of the mill and immediately weighed. For the 43 to 68 kg weight range, pelleted feed was conditioned at 82.7°C resulting in a hot pellet temperature of 89.1°C. Pellet mill production rate was approximately 918 kg per hour. For the 81 to 106 kg weight range, pellets were steam conditioned at approximately 76.9°C which resulted in an approximate hot pellet temperature of 85.2°C. Pellet mill production rate was approximately 936 kg per hour. For the 118 to 144 kg weight range, the pellet die thickness was increased to a 4.8 × 57.2 mm die (L:D 12) to match the approximate amount of fines for pelleted treatments at the feeder as the previous two weight ranges. This resulted in pelleted feed being steam conditioned at approximately 67.0°C and a hot pellet temperature of 81°C. Pellet mill production rate was decreased to approximately 702 kg per hour. For all weight ranges, pellets were cooled (OP-FLO™ AIR COOLER; Bliss Industries, Ponca City, OK) and subsequently screened with a #5 (4.0 mm) screen (Gentle Roll; EBM Manufacturing, Inc. Norfolk, NE) to separate pellets and fines. Screened pellets were collected and a predetermined amount of pellets were then twice passed through a single pair crumble roll (Eco Roll 7; Cañon City, CO) to create fines that are similar in particle size to those created during pellet production to serve as the pellet fines that were blended to achieve the treatments diets.

Pigs were weighed on days 0, 7, 14, and 20 or 21 to determine average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F). The presence of pellet fines at the feeder were monitored for each weight range by probing three random feeders per treatment each week using a hollow tube probe. All feeder probes were collected by probing each feeder on the left side, center, and right side of the feeder hopper. Feed samples were then screened using a #5 screen (4.0 mm). The percentage fines were then calculated by dividing the amount of pellets remaining after screening by the total weight of the sample. At the completion of each weight range, representative samples for each treatment were analyzed for proximate analysis including dry matter (DM), crude protein (CP), crude fiber, crude fat, and ash (Table 3; Ward Laboratories Inc., Kearney, NE).

Experiment 2

A total of 314 pigs (600 × 241 DNA, Columbus, NE; initially 52.4 kg;) were used in a 76-day growth assay to determine the effects of pellet die thickness and removal of pellet fines on growth performance and carcass characteristics. A common diet was formulated to meet or exceed NRC (NRC, 2012) requirement estimates for each of three dietary phases based on target pig weight with diet form as the only difference (Table 5). Treatments consisted of a mash, diets pelleted using a 4.0 × 35 mm pellet mill die (L:D 8.75) fed as-is, diets pelleted using a 4.0 × 22 mm pellet mill die (L:D 5.5) fed as-is, screened pellets from a 4.0 × 22 mm (L:D 5.5) pellet mill die, and pellet fines. Corn was ground using a 3-high roller mill (9 × 24, RMS Roller-Grinder, Harrisburg, SD) to achieve a target particle size of 500 to 600-μm ground corn. Diets were then batched in a 907-kg dual ribbon mixer (Model MX-40, Hayes-Stolz Industrial Manufacturing Co., Burleson, TX) prior to either pelleting or sending to the research farm as mash feed. Pelleted treatments were steam conditioned for approximately 30 s (California Pellet Mill 18 INF 6.5) and subsequently pelleted using a 100-horsepower pellet mill (California Pellet Mill, 3016-4). Naturally created pellet fines were screened with a 3.89 mm screen (GentleRoll; EBM Manufacturing, Inc., Norfolk, NE) and mixed with mechanically created pellet fines from a 4.0 × 22 mm pellet mill die (L:D 5.5) that were ground to a similar particle size using the 3-high roller mill used to grind the corn.

Pelleted treatments were steam conditioned to approximately 83℃ (Table 6). Pellet mill production rates were collected from the front of the pellet mill for 10 seconds and immediately weighed. Hot pellet temperatures were collected using a thermos with a thermometer placed in the lid with the highest temperature being recorded. Pellet mill electrical consumption was recorded at the time of pellet mill production rate and hot pellet temperature sample collection. During the pelleting run, 5 pellet samples were collected at evenly spaced times from the transition prior to the bucket elevator. Pellet durability index (PDI) was analyzed with the New Holmen 100 (TEKPRO, North Walsham, UK), 30s test. Pellets were screened using a #6 (3.4 mm) sieve, 100-g of screened pellets were placed in the chamber and air agitated for 30s. Pellets were then removed from the chamber and sieved once more to remove any residual pellet fines and subsequently weighed. Pellet durability index scores were calculated by dividing the amount of pellets after testing and screening by the initial pellet weight. Pellet durability index samples were completed in duplicate.

As in Exp. 1, feed samples were collected at the farm weekly by probing 3 random feeders per treatment to analyze the percentage fines at the feeder. All feeder probes were collected by probing each feeder on the left side, center, and right side of the feeder hopper using a hollow tube probe. Samples were then composited to create representative samples for proximate analysis. Representative samples from each treatment and dietary feeding phase were analyzed for DM, CP, neutral detergent fiber (NDF), crude fat, and ash (Ward Laboratories, Inc. Kearney, NE).

Pens were weighed on day 0 and divided into 1 of 7 blocks based on average pen weight. Pen weights were collected approximately every 14 d. At the conclusion of the experiment (day 76), pens were weighed followed by individual pig weight collection at the Kansas State Swine Teaching and Research Center prior to carcass data collection (Triumph Foods; St. Joseph, MO). Carcass data collection consisted of hot carcass weight, carcass yield, loin depth (mm), backfat depth (mm), and percentage lean. Loin and backfat depths were measured with an optical probe (Fat-O-Meter, SFK, Herley, Denmark). Dressing percentage was calculated by dividing individual pig hot carcass weight by the corresponding individual live pig weights collected at the farm. Percentage lean was calculated using a proprietary equation of the processing facility.

STATISTICAL ANALYSIS

Experiment 1

Data were analyzed as a randomized complete block design using the PROC-GLIMMIX procedure of SAS (SAS Institute, INC., Cary, NC). Pen was the experimental unit in all experiments with weight blocks as the blocking factor. Dunnett's test was performed with pigs fed mash serving as the control with pigs fed pelleted treatments being compared to pigs fed mash. Linear and quadratic contrasts were constructed with the actual percent fines from feeders using the PROC ILM procedure for unequally spaced treatments. Each weight range was analyzed separately. Results were considered significant if $P \leq 0.05$ and a trend if $P \leq 0.10$.

Experiment 2

Data were analyzed as a randomized complete block design using the PROC-GLIMMIX procedure of SAS (SAS Institute, INC., Cary, NC). Pen was the experimental unit with weight block as the blocking factor for growth performance analysis. Carcass data was analyzed with individual pig measurements serving as the observational unit, pen as the experimental unit and average initial weight serving as the block. Pairwise comparison was used to analyze results from both the growth performances and carcass characteristics utilizing Tukey adjustment for carcass characteristic analysis. Results were considered significant if $P \leq 0.05$ and a trend if $P \leq 0.10$.

RESULTS

Experiment 1: 43 to 68 kg

The conditioning temperature was 83°C which resulted in a hot pellet temperature of 89°C (Table 2). Pellet mill production rate was 917 kg per hour. Proximate analyses were similar across all treatments within the weight range dietary formulation (Table 3).

Pelleted treatments resulted in 12.5, 46.4, 67.6, and 90.4% fines at the feeder for blend of screened pellets, 25, 50, or 75% pellet fines (Table 4). There was no evidence of a difference in ADFI or ADG between pigs fed any pelleted diet when compared to the mash diet. Average daily feed intake increased (linear, $P = 0.006$) for pigs fed pelleted treatment as percent fines at the feeder increased. Pig G:F improved ($P < 0.05$) when fed pellets with 12.5% fines compared to those fed the mash diet. As percentage fines at the feeder decreased, GF increased (linear, $P = 0.0016$) for pigs fed pelleted treatments.

Experiment 1: 81 to 106 kg

Diets were steam conditioned at 77°C, resulting in a hot pellet temperature of 85°C (Table 2). Pellet mill throughput was similar to Exp. 1: 43 to 68 kg at 936 kg per hour. Proximate analyses were similar across all treatments within the current weight range dietary formulation (Table 3).

Pelleted treatments resulted in 15.5, 43.6, 60.5, and 86.0% fines at the feeder for treatments that targeted screened pellets, 25, 50, and 75% pellet fines, respectively (Table 4). There was no evidence of a difference in ADG for pigs fed any of the pelleted treatments when compared to the mash diet. Pigs fed pellets with 86.0% fines had a tendency for increased ($P < 0.1$) ADFI when compared to those fed the mash diet. Pigs fed pelleted diets had an increased (linear, $P = 0.016$) ADFI as the percentage fines increased at the feeder. Pigs fed pellet diets with 15.5% fines had improved ($P < 0.05$) G:F when compared to those fed mash diets. Whereas, pigs fed pellets containing 86.0% fines had a tendency for decreased ($P < 0.1$) G:F compared to pigs fed the mash diet. Pig G:F improved (linear, $P = 0.001$) as percentage fines decreased at the feeder.

Experiment 1: 118 to 144 kg

Diets were pelleted on the same pellet mill as the previous two experiments; however, a pellet mill die change was needed to maintain consistent percentage of fines at the feeder as compared to the previous two experiments. A 4.8 × 57.2 mm (L:D 12) die was used to achieve a similar high-quality pellet as the previous two weight ranges (41 to 68 kg and 81 to 106 kg). Mash feed was conditioned at 67°C, resulting in a hot pellet temperature of 81°C. The L:D 12 die resulted in a production rate of 702 kg per hour (Table 2).

Pelleted treatments resulted in 9.6, 41.8, 65.1, and 83.6% fines at the feeder for target treatments of screened pellets, 25, 50, and 75% fines at the feeder, respectively (Table 4). There was no evidence of a difference for ADG in pellets fed any of the pelleted diets when compared to the mash diet. Pigs fed pellets with 83.6% fines had a tendency for increased ($P < 0.1$) ADFI when compared to pigs fed the mash diet. Pelleted treatments containing 9.6 and 41.8% fines had improved ($P < 0.05$) G:F when compared to those fed the mash diet. Pigs fed 65.1% fines had a tendency for improved ($P < 0.1$) G:F compared to pigs fed the mash diet. As percentage fines at the feeder increased, G:F decreased (linear, $P = 0.005$) for pigs fed pelleted treatments.

Experiment 2

From d 0 to 76, pelleted treatments yielded 28, 42, and 37% fines at the feeder (Table 7) for feed pelleted using pellet dies L:D 8.75, L:D 5.5 fed as-is, and L:D 5.5 screened, respectively. Pigs fed L:D 8.75 pellets had increased ($P < 0.05$) d 76 BW compared pigs fed either mash or L:D 5.5 pellets fed as-is while pigs fed screened L:D 5.5 pellets and only pellet fines had intermediate d 76 BW (Table 7). Overall, pigs fed L:D 8.75 pellets had improved ($P < 0.05$) ADG compared to pigs fed mash, L:D 5.5 pellets fed as-is, or pellet fines. There was no evidence of differences in ADFI for any of the treatments. Pigs fed L:D 8.75 pellets had improved ($P < 0.05$) G:F when compared to pigs fed mash or L:D 5.5 pellets as-is, while pigs fed screened L:D 5.5 pellets or fines were intermediate. Pigs fed L:D 8.75 pellets had improved (P < 0.05) HCW's compared to pigs fed L:D 5.5 pellets as-is with pigs fed all other treatments intermediate. There was no evidence of differences for pigs fed any of the treatments for carcass yield, backfat thickness, loin depth, or percentage lean.

DISCUSSION

Pelleting swine diets is commonly used to improve nutrient utilization, feed efficiency, feed handling characteristics and bulk density. Most of the improvement in swine feed efficiency due to pelleting can be attributed to a decrease in feed wastage (Stark et al., 1994). Previous research has demonstrated these improvements in growth performances for pigs fed pelleted diets compared to pigs fed mashed diets (Stark et al., 1994; Wondra et al., 1995; De Jong et al., 2016). Most notably, the consistent improvement in growth performances across these studies have been improved G:F by 4 to 7% for pigs fed pellets compared to those fed mash diets (De Jong et al., 2016; Williams et al., 2021). However, improvements in ADG were inconsistent across studies. Myers et al. (2013) observed that providing pellets provided no improvements in pig ADG. Whereas Paulk and Hancock (2015) observed a 5% improvement in ADG for pigs fed pelleted diets compared to pigs fed mash.

For Exp. 1 reported herein, pigs were provided pellets with varying amounts of pellet fines. During the experiment, pigs that were fed pellets < 16% had an increased G:F range of 4 to 9% compared to pigs fed mash. Previous studies have shown a range of improvements to G:F of 4% (De Jong et al., 2013) to 13% (Nemechek et al., 2015) when fed pelleted diets with comparable amounts of pellet fines to the present experiment at the feeder.

Although previous research has demonstrated consistent improvements in feed efficiency when pigs are fed pelleted diets, the degree of this response depends on pellet quality or the percentage of fines at the feeder. Myers et al. (2013) observed that pigs presented pellets with >30% fines at the feeder had reduced G:F compared to pigs fed mash diets. In contrast, recent research demonstrated an improvement in G:F when pigs were fed diets containing an average of 40% fines throughout the grow-finish period compared to those fed mash diets (Williams et al., 2021). For the 43 to 68 kg and 81 to 106 kg pigs reported herein, only the screened pellet treatments containing 12.5 and 15.5% fines at the feeder had an improvement in G:F compared to pigs fed mash diets; however, for 118 to 144 kg, pigs fed up to 65% fines tended to have improved G:F compared to those fed mash diets. This could potentially be explained by the decrease in livable space/pig at this weight range and activity level for pigs. Pigs would have less space to sort through fines at the feeder and were spending more time eating the pellet blends that were provided. In addition, increasing the percentage of fines from 12.5 to 90.4%, 15.5 to 86.0%, and 9.6 to 83.6% reduced G:F of pigs by 5.9, 8.6, and 6.4% for the 43 to 68 kg, 81 to 106 kg, and 118 to 144 kg pigs, respectively. This is similar to previous research which has determined the effect of percentage fines of pelleted diets on pig G:F (Stark at al., 1994; Schell and Van Heugten 1998; and Nemechek et al., 2015).

Experimental diets from Exp. 1 and the published literature have historically created pellet quality treatments by blending screened pellets with created pellet fines. The goal for Exp. 2 was to create treatments by pelleting diets using different die thicknesses or screening pellets prior to shipment to the farm. In the current study two different pellet mill die thicknesses were used. It was hypothesized that increasing die L:D ratio would reduce pellet fines at the feeder due to nearly doubling the retention time of feed spent in the die. This allows particles to adhere and produce a better-quality pellet. This resulted in large numerical differences in pellet durability index scores and percentage fines at the feeder between the diets pelleted using the

L:D 8.75 compared to the L:D 5.5. Throughout the experiment diets pelleted using the L:D 8.75, L:D 5.5 as-is, or L:D 5.5 screened resulted in 27.8, 42.8, and 36.9% fines at the feeder. Pigs fed diets pelleted using the L:D 8.75 (27% fines) had improved G:F compared to those fed mash feed. This was similar to the results observed in Exp. 1. There was no evidence of difference in G:F between pigs fed diets pelleted using L:D 5.5 (36.9% fines) or screened pellets (36.9 % fines) and the mash control. This is similar to 43 to 68 kg and 81 to 106 kg in Exp. 1; however, for 118 to 144 kg, pigs fed up to 65% fines tended to have improved G:F compared to those fed mash diets.

In Exp. 2 conducted herein, pigs fed diets pelleted using L:D 8.75 die had increased ADG and BW compared to pigs fed mash or diets pelleted using the L:D 5.5 die fed as-is, respectively. The influence of pelleting diets on pig ADG has been variable among studies. Previous research has demonstrated similar improvements in gain when pigs are fed pelleted diets compared to the mash control. (Paulk and Hancock, 2015; Nemechek et al., 2015; Nemechek et al., 2016). However, there was no evidence of difference in ADG in pigs fed pellets in Exp. 1. Previous research also observed no differences in ADG when fed pelleted diets compared to a mash control (Ball et al., 2014; de Jong et al., 2016; Myers et al., 2013). In addition, Exp. 1 and previous research has demonstrated no evidence of differences in BW gain due to percent fines at the feeder (Nemechek et al., 2015; Nemechek et al., 2016). Experiments 1 and 2 differed in their designs due to emphasis being placed on specific weight range responses to pellet quality for Exp. 1 while Exp. 2 was designed to evaluate the impact of pellet die thicknesses across the entirety of the grow-finish phase. There were no statistical differences in ADG across Exp. 1; however, when the L:D 12 pellet mill die was used in the heaviest weight range (116 to 144 kg), pigs fed pellets with 10% fines had a numerically greater ADG. However, pellet mill throughput with the L:D 12 pellet mill die was reduced by 25% compared to pellets produced with the L:D 6.67 die. The numerical difference in ADG served as a baseline of potential responses to increased pellet die thickness, which was tested in Exp. 2.

Pigs fed L:D 8.75 (27.82% fines) pellets had increased HCW by 3.8% compared to pigs fed L:D 5.5 pellets fed as-is (42.10% fines). Previous research has shown improvements in final BW and HCW for pigs fed pellet diets compared to pigs fed mash feed but no studies have shown differences in carcass characteristics between pelleted diets with varying levels of fines (Nemechek et al. 2015; Paulk and Hancock, 2015; Williams et al. 2021). Previous research by Overholt et al. (2016) observed a decrease in carcass yield for pigs fed pelleted diets and attributed the reduction in yield to the increase in fat thickness. However, no differences were observed for pigs fed pelleted treatments or mash for carcass yield, backfat thickness, loin depth, or percentage lean within the current experiment.

CONCLUSIONS

In conclusion, these experiments demonstrate reducing the amount of pellet fines at the feeder increases pig G:F. Pigs weighing up to 106 kg had improved G:F when provided with minimal fines while pigs weighing up to 144 kg had improvements in G:F up to 65% fines showing this weight range of pigs are not as susceptible to poor pellet quality. These experiments supported previous research with G:F responses while ADG responses were variable between experiments. Increasing pellet die thickness increased pig G:F responses in both experiments.

Table 2.1. Composition of experimental diets, Exp. 1 (as-fed basis)[1]

	Weight range, kg		
Item	43 to 68	81 to 106	118 to144
Ingredient, %			
Corn	73.54	81.08	81.65
Soybean meal, (46.5% CP)	21.23	14.15	13.8
Corn oil	1.50	1.50	1.50
Calcium carbonate	0.75	0.65	0.60
Calcium phosphate (monocalcium P)	0.50	0.28	0.10
Sodium chloride	0.50	0.55	0.50
L-Lys-HCl	0.45	0.39	0.38
DL-Met	0.11	0.06	0.09
L-Thr	0.14	0.12	0.16
L-Trp	0.04	0.04	0.04
L-Val	0.09	0.05	0.04
Vitamin premix with phytase[2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Pellet binder[4]	0.75	0.75	0.75
TOTAL	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) AA %			
Lys	1.05	0.83	0.81
Ile:Lys	55	55	56
Leu:Lys	123	135	138
Met:Lys	33	31	36
Met & Cys:Lys	55	56	62
Thr:Lys	60	61	68
Trp:Lys	19.2	19.1	19.3
Val:Lys	69	69	69
His:Lys	37	39	40
ME,kcal/kg	3,362	3,362	3,386
NE, kcal/kg	2,551	2,581	2,608
CP, %	16.9	14.3	13.9
Ca, %	0.54	0.54	0.38
P, %	0.45	0.44	0.33

[1]Experimental diets were mixed at Hubbard Feeds (Beloit, KS) and shipped to O.H. Kruse Feed Technology and Innovation for pelleting. All treatments within experiments were fed the same formulation diet with respect to weight ranges (43 to 68, 81 to 106, 118 to 144 kg).

[2]Provided per kilogram of vitamin premix: 165,346 IU Vitamin A, 661,376 IU Vitamin D_3, 17,637 IU Vitamin E, 13 mg Vitamin B_{12}, 1,323 mg menadione, 3,307 mg riboflavin, 11,023 mg d-Pantothenic Acid, 19,841 mg niacin, also contained Ronozyme HiPhos GT 20000, 1,226 FYT/kg with an estimated release of 0.14% standardized total tract P.

[3]Provided per kilogram of trace mineral premix: of 73 g Fe from ferrous sulfate, 73 g Zn from zinc sulfate, 22 g Mn from manganous oxide, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, 198 mg Se from sodium selenite.
[4]Ameri-Bond 2X, Borregaard, Sarpsborg, Norway.

Table 2.2. Feed production records for pelleting experimental diets, Exp. 1[1]

Item	43 to 68 kg[2]	81 to 106 kg[2]	118 to 144 kg[3]
Production rate, kg/h	918.0	936.0	702.0
Conditioning temperature, ℃	82.7	76.9	67.0
Hot pellet temperature, ℃	89.1	85.2	81.0

[1]Pellets were manufactured by a 30-horsepower pellet mill (1012-2 HD Master Model, California Pellet Mill, Crawfordsville, IN).

[2]43-68 and 81-106 kg dietary treatments were pelleted with a 4.8 × 31.8 mm die to (L:D 6.67).

[3]118 to 144 kg dietary treatments were pelleted with 4.8 × 57.2 mm die (L:D 12).

Table 2.3. Chemical analysis of experimental diets, Exp. 1 (as-fed basis)[1]

Item	Mash control[2]	Screened pellets[2]	Percentage fines 25[2]	Percentage fines 50[2]	Percentage fines 75[2]
43 to 68 kg					
Moisture	11.48	11.47	11.91	11.66	12.17
Crude protein	16.40	16.50	16.90	16.70	16.10
Crude fiber	2.90	2.80	2.50	2.70	2.70
Crude fat	3.40	3.40	3.10	3.50	3.40
Ash	3.76	3.75	3.86	3.85	3.61
81to 106 kg					
Moisture	10.68	11.70	11.50	11.26	11.01
Crude protein	13.40	12.70	13.00	12.50	12.70
Crude fiber	0.30	0.60	0.60	0.50	0.70
Crude fat	3.90	3.80	3.70	3.60	3.50
Ash	2.99	2.86	3.04	2.98	3.09
118 to 144 kg					
Moisture	12.79	12.96	12.77	13.45	12.86
Crude protein	13.70	13.30	13.20	13.10	13.20
Crude fiber	2.20	2.20	2.30	2.30	2.50
Crude fat	5.30	5.00	5.00	5.20	5.20
Ash	2.98	2.92	2.95	2.88	2.89

[1]Treatment samples were collected by probing three randomly selected feeders per treatment each week for analysis (Ward Laboratories, Inc., Kearney, NE).

[2]Assigned treatment of either mash control, screened pellets, 25, 50, or 75% fines blended with pellets.

Table 2.4. Effects of increasing pellet fines on growth performance of finishing pigs (Exp. 1)[1]

Item	Mash control[4]	Screened pellets[4]	Percentage fines 25[4]	50[4]	75[4]	SEM	Probability, $P <$[3] Linear	Quadratic
43-68 kg								
Percent fines[2]	---	12.5	46.4	67.6	90.4			
BW, kg								
d 0	43.57	43.59	43.57	43.66	43.60	0.612	0.829	0.970
d20	67.75	67.71	68.22	67.71	68.16	0.776	0.627	0.895
d 0 to 20								
ADG, kg	1.21	1.21	1.22	1.20	1.23	0.021	0.641	0.919
ADFI, kg	2.37	2.27	2.36	2.32	2.45	0.038	0.006	0.558
G:F	0.509	0.532*	0.520	0.519	0.502	0.006	0.002	0.544
81-106 kg								
Percent fines[2]	---	15.5	43.6	60.5	86.0			
BW, kg								
d 0	81.59	81.52	81.58	81.52	81.56	0.838	0.942	0.978
d20	105.36	106.46	105.47	105.76	106.06	1.125	0.682	0.279
d 0 to 21								
ADG, kg	1.13	1.19	1.14	1.15	1.17	0.024	0.608	0.199
ADFI, kg	3.04	3.05	3.01	3.19	3.26†	0.072	0.016	0.388
G:F	0.372	0.390*	0.378	0.362	0.358†	0.004	<0.001	0.505
116-144 kg								
Percent fines[2]	---	9.6	41.8	65.1	83.6			
BW, kg								
d 0	118.45	118.44	118.40	118.36	118.36	1.292	0.876	0.975
d 20	141.07	143.35	142.93	142.77	143.84†	1.542	0.802	0.370
d 0 to 21								
ADG, kg	1.14	1.25	1.23	1.22	1.24	0.034	0.800	0.626
ADFI, kg	3.41	3.47	3.47	3.48	3.69†	0.083	0.12	0.182
G:F	0.333	0.359*	0.353*	0.350†	0.336	0.005	0.005	0.299

[*]Denotes a significant difference of $P \leq 0.05$ when treatments are compared to the mash control.

[†]Denotes a trend $P \leq 0.1$ when treatments are compared to the mash control.

[1]A 3 weight range experiment was conducted on grow-finish age pigs, 43 to 68 kg lasting 20 days, 81 to 106 kg lasting 21 days, 118 to 144 kg lasting 20 days.

[2]Feed samples were collected at the feeder and sifted using a #5 (4.0 mm) sieve. The weight (grams) were then divided by the total sample weight to determine the percentage of pellets and fines.

[3]Dunnets test in SAS with contrasts created with fines percentages at the feeder for each experiment to compare pelleted treatments to mash diet.

[4]Assigned treatment of either mash control, screened pellets, 25, 50, or 75% fines.

Table 2.5. Ingredient Composition of experimental diets for Exp. 2, as-fed basis[1]

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	75.57	80.95	84.97
Soybean meal, Dehull, Sol Extr	20.69	15.83	12.03
Soybean oil	1.00	1.00	1.00
Calcium carbonate	0.75	0.75	0.60
Calcium phosphate (monocalcium)	0.45	0.30	0.10
Sodium chloride	0.50	0.50	0.50
L-Lys-HCl	0.40	0.35	0.35
DL-Met	0.11	0.07	0.07
L-Thr	0.14	0.12	0.12
L-Trp	0.03	0.03	0.03
L-Val	0.06	0.04	0.02
Vitamin premix[2]	0.15	0.13	0.10
Trace mineral premix[3]	0.15	0.13	0.10
Phytase[4]	0.02	0.02	0.02
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) AA %			
Lys	1.00	0.84	0.75
Ile:Lys	57	58	57
Leu:Lys	129	140	146
Met:Lys	34	34	35
Met & Cys:Lys	48	59	62
Thr:Lys	63	64	66
Trp:Lys	18.5	18.8	19.0
Val:Lys	69	70	69
Hist:Lys	49	41	41
Total Lys, %	1.12	0.94	0.84
ME, kcal/kg	3,366	3,379	3,393
NE, kcal/kg	2,513	2,552	2,584

SID Lys:NE, g/Mcal	3.92	3.25	2.87
CP, %	16.7	14.7	13.2
Ca, %	0.51	0.42	0.34
P, %	0.44	0.39	0.33
Available P, %	0.30	0.26	0.21

[1]Experimental diets were batched and mixed using a 907 kg mixer (Model MX-40, Hayes-Stolz Industrial Manufacturing Co., Burleson, TX) at the O.H. Kruse Feed Manufacturing and Innovation Center. Diets were subsequently loaded out for delivery or pelleted with their respective dies (L:D 5.5 or 8.75)

[2]Provided per kilogram of vitamin premix: 1,653,439 IU Vitamin A, 661,376 IU Vitamin D_3, 17,637 IU Vitamin E, 13.2 mg Vitamin B_{12}, 1,323 mg menadione, 3,307 mg riboflavin, 11,023 mg d-Pantothenic Acid, 19,841 mg niacin.

[3]Provided per kilogram of trace mineral premix: of 73 g Fe from ferrous sulfate, 73 g Zn from zinc sulfate, 22 g Mn from manganous oxide, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, 198 mg Se from sodium selenite.

[4]Quantum Blue 10G, AB Vista, Plantation, FL with an estimated release of 0.14% standardized total track P.

Table 2.6. Exp. 2 pellet mill production records for pelleting experimental diets[1]

Diet Form	L:D 8.75[2]	L:D 5.5, as is[3]	L:D 5.5, screened[3,4]
Phase 1			
Production rate, MT/hr[6]	3.48	4.38	4.48
Conditioning temperature ℃	82.46	82.09	82.31
Hot pellet temperature ℃	84.04	82.81	82.76
kWh	13.26	10.96	10.62
Pellet durability index, %[7]	76.80	51.41	52.57
Phase 2			
Production rate, MT/hr[6]	3.27	4.38	4.35
Conditioning temperature, ℃	82.48	82.30	82.28
Hot pellet temperature, ℃	83.83	82.65	82.39
kWh	13.85	10.22	10.34
Pellet durability index, %[7]	80.12	38.38	49.58
Phase 3			
Production rate, MT/hr[6]	3.27	4.23	4.44
Conditioning temperature, ℃	82.62	81.74	82.78
Hot pellet temperature, ℃	85.22	82.00	82.80
kWh	14.05	10.66	10.00
Pellet durability index, %[7]	75.27	36.64	54.51

[1]Pellets were steam conditioned (California Pellet Mill, 18 INF 6.5) and subsequently pelleted with a 100-horsepower pellet mill (California Pellet Mill, 3016-4).

[2]Pelleted using a 4.0 × 35 mm (L:D 8.75) die.

[3]Pelleted using a 4.0 × 22 mm (L:D 5.5).

[4]Pellets sieved using a 3.98 mm screen.

[5]Pellets ground using a three high roller mill to create mechanically created pellet fines.

[6]Metric tonnes per hour.

[7]Pellet durability index scores determined by a 30-second Holmen 100 test.

Table 2.7. The effects of pellet die thickness and pellet fines on growth performances of pigs from 52 to 146 kg[1]

	Diet form						
	Mash	L:D 8.75[2]	L:D 5.5, as-is[3]	L:D 5.5, screened[3,4]	Fines[4,5]	SEM	Probability (*P*<)
BW d 76, kg	140.23[c]	145.58[a]	141.00[b,c]	143.10[a,b]	143.39[a,b]	1.142	0.005
d 0 to 76							
Fines at feeder, %[6]	-	27.82	42.10	36.90	-		
ADG, kg	1.15[c]	1.23[a]	1.16[c]	1.20[a,b]	1.18[b,c]	0.013	0.002
ADFI, kg	3.10	3.15	3.08	3.13	3.10	0.045	0.775
G:F	0.372[b]	0.389[a]	0.377[b]	0.383[a,b]	0.381[a,b]	0.004	0.041
HCW[7], kg	105.55[a,b]	108.24[a]	103.74[b]	106.79[a,b]	105.60[a,b]	1.140	0.052
Carcass yield, %	74.89	74.74	74.22	74.70	74.61	0.193	0.163
Back fat thickness, mm	17.39	17.47	16.70	17.20	16.92	0.394	0.613
Loin depth, mm	66.19	66.19	66.38	65.95	66.85	0.559	0.827
Lean[8], %	53.71	53.74	54.05	53.74	53.94	0.182	0.590

[a-e]Means within row with differing superscripts are significantly different ($P < 0.05$).

[1]A total of 314 pigs (initially 52.39 ± 1.51 kg) were used in a 76-day growth assay to determine the effects of pellet die thickness on pig growth performance.

[3]Pellets extruded through a 4.0 × 22 mm die (L:D 5.5) and fed as is.

[4]Pellets screened with a 3.89 mm Gentle Roll screen.

[5]Pellets ground using a three high roller mill to create mechanically created pellet fines.

[6]Composite of 3 random feeder probes per treatment each week during feeding phase to determine presence of fines.

[7]Hot carcass weight.

[8]Percent lean calculated using a proprietary formula from the packing facility.

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