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K-State Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

SWINE DAY 2012

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SWINE DAY 2012

Foreword

It is with great pleasure that we present the 2012 Swine Industry Day Report of Progress. This report contains updates and summaries of applied and basic research conducted at Kansas State University during the past year. We hope that the information will be of benefit as we attempt to meet the needs of the Kansas swine industry.

2012 Swine Day Report of Progress Editors

Bob Goodband   Mike Tokach   Steve Dritz   Joel DeRouchey

Standard Abbreviations

ADG = average daily gain
ADF = acid detergent fiber
ADFI = average daily feed intake
AI = artificial insemination
avg. = average
bu = bushel
BW = body weight
cm = centimeter(s)
CP = crude protein
CV = coefficient of variation
cwt = 100 lb
d = day(s)
DE = digestible energy
DM = dry matter
DMI = dry matter intake
F/G = feed efficiency
ft = foot(feet)
ft^2 = square foot(feet)
g = gram(s)
µg = microgram(s), .001 mg
gal = gallon(s)
GE = gross energy
h = hour(s)
HCW = hot carcass weight
in. = inch(es)
IU = international unit(s)
kg = kilogram(s)
kcal = kilocalorie(s)
kWh = kilowatt hour(s)
lb = pound(s)
Mcal = megacalorie(s)
ME = metabolizable energy
mEq = milliequivalent(s)
min = minute(s)
mg = milligram(s)
mL = cc (cubic centimeters)
mm = millimeter(s)
mo = month(s)
MUFA = monounsaturated fatty acid
N = nitrogen
NE = net energy
NDF = neutral detergent fiber
ng = nanogram(s), .001 Fg
no. = number
NRC = National Research Council
ppb = parts per billion
ppm = parts per million
psi = pounds per sq. in.
PUFA = polyunsaturated fatty acid
sec = second(s)
SE = standard error
SEM = standard error of the mean
SEW = segregated early weaning
SFA = saturated fatty acid
UFA = unsaturated fatty acid
wk = week(s)
wt = weight(s)
yr = year(s)

K-State Vitamin and Trace Mineral Premixes

Diets listed in this report contain the following vitamin and trace mineral premixes unless otherwise specified.

- Trace mineral premix: Each pound of premix contains 12 g Mn, 50 g Fe, 50 g Zn, 5 g Cu, 90 mg I, and 90 mg Se.
- Vitamin premix: Each pound of premix contains 2,000,000 IU vitamin A, 300,000 IU vitamin D_3, 8,000 IU vitamin E, 800 mg menadione, 1,500 mg riboflavin, 5,000 mg pantothenic acid, 9,000 mg niacin, and 7 mg vitamin B_{12}.
- Sow add pack: Each pound of premix contains 100,000 mg choline, 40 mg biotin, 300 mg folic acid, and 900 mg pyridoxine.

Note

Some of the research reported here was carried out under special FDA clearances that apply only to investigational uses at approved research institutions. Materials that require FDA clearances may be used in the field only at the levels and for the use specified in that clearance.

Biological Variability and Chances of Error

Variability among individual animals in an experiment leads to problems in interpreting the results. Animals on treatment X may have higher average daily gains than those on treatment Y, but variability within treatments may indicate that the differences in production between X and Y were not the result of the treatment alone. Statistical analysis allows us to calculate the probability that such differences are from treatment rather than from chance.

In some of the articles herein, you will see the notation "$P < 0.05$." That means the probability of the differences resulting from chance is less than 5%. If two averages are said to be "significantly different," the probability is less than 5% that the difference is from chance or the probability exceeds 95% that the difference resulted from the treatments applied.

Some papers report correlations or measures of the relationship between traits. The relationship may be positive (both traits tend to get larger or smaller together) or negative (as one trait gets larger, the other gets smaller). A perfect correlation is one (+1 or -1). If there is no relationship, the correlation is zero.

In other papers, you may see an average given as 2.5 ± 0.1. The 2.5 is the average; 0.1 is the "standard error." The standard error is calculated to be 68% certain that the real average (with unlimited number of animals) would fall within one standard error from the average, in this case between 2.4 and 2.6.

Many animals per treatment, replicating treatments several times, and using uniform animals increase the probability of finding real differences when they exist. Statistical analysis allows more valid interpretation of the results, regardless of the number of animals. In all the research reported herein, statistical analyses are included to increase the confidence you can place in the results.

Feed Efficiency in Swine: A Survey of Current Knowledge[1]

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Summary
Pork producers and advisers to the swine industry were surveyed about their knowledge of feed efficiency. The questionnaire was designed to accomplish three objectives: (a) determine the level of knowledge related to feed efficiency topics, (b) identify production practices being used that influence feed efficiency, and (c) identify information gaps or areas requiring additional knowledge to further improve feed efficiency.

Producer responses imply that they are unfamiliar with information behind the effects of fat inclusion, particle size reduction, feed additives, and thermal environment on feed efficiency. Many were not sure which energy system to use for evaluating dietary energy. Consultants and individuals in academia had the highest percentage of correct answers for the knowledge questions, but less than half identified the correct response when asked how reducing particle size affects feed efficiency, and very few correctly answered the question on how thermal environment affects feed efficiency. This result suggests the need for more information and education in these two topic areas.

Respondents who classified themselves as "Other" frequently replied "Not sure" to many of the knowledge-based questions, and also to several production practice questions, which may be due to the great diversity of occupations within the group. When responses were sorted by years of experience, a majority of individuals with less experience, specifically those with 0 to 5 years, had higher percentages of "Not sure" responses, which may be related to their unfamiliarity to specific industry practices and the knowledge behind those practices.

A majority of participants used or recommended using feed additives to improve feed efficiency; however, they indicated that they don't use other production practices such as fine-grinding cereal grains below 400 µm or pelleting finishing diets because of economic or system constraints or because these processing technologies are not available in their feed mills.

Extension education about current knowledge and production practices that are already proven should be expanded to provide this information in an easy-to-access format for the swine industry. Ultimately, successful dissemination of this information should help producers and swine operations lower input costs by improving the efficiency of their feed utilization.

Key words: feed efficiency, swine survey, swine industry

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[1] This project was supported by National Research Initiative Competitive Grant no. 2011-68004-30336 from the USDA National Institute of Food and Agriculture.

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Introduction

Feed represents the largest input expense for U.S. pork producers, usually totaling more than 60% of the total cost of production. Increased non-feed use for the U.S. corn crop has led to distinct rises in prices, and crop supply fluctuation adds to the variability in ingredient costs. Nationwide, whole-herd feed conversion (lb feed/lb pork) is approximately 3 to 1. Improving feed efficiency by one unit change (e.g., 3.00 to 2.99) represents approximately 140,000 tons of feed annually, or feed cost savings of ~$28 million dollars. Efforts to fully adopt existing knowledge to optimize feed efficiency by the U.S. pork industry will improve the long-term competitiveness of the U.S. pork industry and the sustainability of food supplies.

This survey was developed to identify the current state of knowledge and the production practices used in the swine industry. The questionnaire was designed to accomplish three objectives: (1) determine the industry level of knowledge related to feed efficiency topics, (2) identify production practices being used that influence feed efficiency, and (3) identify information gaps or areas requiring additional knowledge to further improve feed efficiency. Conclusions drawn from this study will be used to assemble extension education programs to rapidly disseminate information to producers and industry workers on current and innovative information that may improve feed efficiency and to aid in future research initiatives.

Procedures

The procedures for this survey were approved by the Kansas State University Committee for Research Involving Human Subjects. The survey was web-based and created using the Axio Survey Creation Tool (https://online.ksu.edu/Survey/).

The subjects of this survey were individuals with their primary occupation in the swine industry. Most participants were from the United States, but international responses were received. The survey was made available via the internet from November 1, 2011, through March 1, 2012. Subjects targeted for the questionnaire were asked to participate through press releases advertised in popular press magazines including National Hog Farmer (www.nationalhogfarmer.com), Pork Magazine (www.porknetwork.com), and Feedstuffs Weekly Newspaper for Agribusiness (www.Feedstuffs.com). Emails with the press release were distributed to digital subscribers of those magazines, producer and allied industry email address lists used by K-State Swine Research and Extension, and individuals who registered for the International Conference on Feed Efficiency in Swine that was held November, 2011, in Omaha, NE. A link to the survey website was available on K-State's Swine Research and Extension website (www.KSUswine.org).

Individuals who participated in the survey were not required to answer all questions; therefore, results were summarized based on responses to individual questions. Total responses for individual questions ranged from 123 to 205.

Two demographic questions were asked to identify the population of respondents and to summarize the answers received for questions within the survey. The first was designed to allow respondents to categorize themselves by the segment of the swine industry that they represented as a primary occupation (pork producer, consultant to the swine industry, education, or other; Table 1). Out of 205 individuals who responded to the first question, the largest percentage, 33%, identified themselves as consultants to the swine industry. An additional 28% identified themselves as producers, and 23% categorized themselves as "Other." Respondents who identified themselves as "Other" were asked to describe their role in the swine industry. A majority of those individuals said they were graduate students, media reporters/editors, feed manufacturers, meat packers, technical support representatives for production systems, and pharmaceutical/vaccine sales representatives. The second question was designed to categorize participants by their number of years of experience working in the swine industry (0 to 5 years, 5 to 10 years, 10 to 20 years, 20+ years; Table 2). The greatest majority (53%) of individuals responded that they have more than 20 years of swine industry experience, and 21% had 10 to 20 years of experience.

After establishing demographics of the sampled population, a series of knowledge-based, production practice, and discovery questions were asked to help achieve the objectives of the survey. Knowledge and production practice questions were delivered in a multiple-choice format, and possible answers included "Not sure" and "Other" options. Several production practice questions also branched into sub-questions depending on how respondents answered the main question. Branching sub-questions allowed for further data collection to better understand reasoning behind production practices utilized in the field, which will help extension educators identify critical control points within production systems as they pertain to feed efficiency. The discovery questions were designed so respondents could rank a predetermined topic area priority list from 1 to 10. To summarize the discovery questions, the average rank of each topic area was used to determine an overall ranking from the highest to lowest priority for future research and emphasis.

Results and Discussion

Defining Feed Efficiency

Survey respondents were asked to define feed efficiency as it relates to swine production; in response, 71% answered that feed efficiency is the amount of feed needed for one unit of live animal weight gain, and 15% answered with the amount of feed needed to gain one unit of carcass weight (Table 3). Both of these answers were considered correct, because feed efficiency can be defined on a live weight or carcass weight basis.

Dietary Energy

Individuals were asked to distinguish which dietary energy system they utilize when formulating diets. A total of 129 individuals responded (Table 4); 52% answered that they utilize ME, and 23% responded that they use NE. Based on demographics, 34% of producers (32) and 58% of respondents with 0 to 5 years of experience (12) were not sure. Participants were also asked how much of an improvement in feed efficiency can be expected by increasing dietary fat by 1% (Table 11; Question 1). In total, 138 respondents answered, with 41% answering correctly (2%), 30% answered incorrectly, and 27% responding "Not sure" (Table 12; Question 1). Of the producers who responded to this question (39), 31% answered correctly, whereas 44% answered "Not sure." In contrast, 63% of consultants answered this question correctly, but only 17% of respondents in the "Other" category for profession answered correctly (Table 13; Question 1). When responses are sorted by years of experience, 58% of respondents with less than 5 years and 47% of individuals with 5 to 10 years of experience answered "Not sure" (Table 14; Question 1).

Grinding/Particle Size

A total of 164 respondents answered the question asking what cereal grain particle size is used or recommended for swine diets (Table 5). Most respondents (73%) indicated below 700 µm, but only 4% of respondents grind or recommend grinding grain below 400 µm, and 19% were not sure. A total of 45% of individuals who categorized their profession as "Other" (33) and 53% of individuals with 0 to 5 years of experience (17) responded "Not sure." If respondents answered with a particle size greater than 400 µm, they were asked a branched question to determine why they do not grind to a finer particle size. The most common reason (35% of responses) was that flowability or handling characteristics cause problems in the feeding system. Participants were also asked how much of an improvement in feed efficiency can result from decreasing the particle size of grain by 100 µm (Table 11; Question 2). In total, 160 individuals answered, 36% answered correctly (1.1 to 1.4%,) 31% answered "Not sure," and 30% answered incorrectly (Table 12; Question 2). Of the producers who responded to this question (44), only 27% answered correctly (Table 13; Question 2), and only 25% of individuals with less than 5 years of experience (12) answered the question correctly (Table 14; Question 2).

Pelleting

Participants were asked if they feed pelleted or recommend pelleting finishing diets. A total of 151 individuals answered, 59% replied "No," and 41% replied "Yes" (Table 6). Interestingly, 70% of individuals categorized as "Other" answered "Yes," whereas most producers, consultants, and academic participants answered "No." Individuals who answered "No" were then asked why they do not pellet or recommend pelleting finishing diets, and respondents could check all answers that applied. A total of 148 responses were returned; 29% indicated pelleting was too expensive or that it was not available at their local feed mill. These were clearly the most common reasons why individuals do not feed pelleted finishing diets. When asked how much of an improvement can be expected from feeding high-quality pellets (Table 11; Question 3), 70% of responses (157) answered correctly, with 2 to 6% (Table 12; Question 3). This result represented correct responses from 70% of producers (44), 80% of consultants (56), 62% of those in academia (26), and 52% of individuals who categorized themselves as "Other" (31; Table 13; Question 3). Additionally, 60% or more within each age category answered correctly, indicating a high knowledge level across the industry about pelleting diets for swine (Table 14; Question 3).

Extrusion/Expanding Processing

Extrusion and expanding are used in human food preparation, in pet food, and aquaculture products. Although it has not been used frequently for swine feed, improvements in pellet quality, and thus feed efficiency, have been seen when used for swine diets. Participants were asked if they recommend or use extrusion or expanding processing in any of their swine diets. A total of 147 respondents answered, with 93% of respondents answering no and only 7% answering "Yes" (Table 7). Participants were sent to branched questions depending on their response; if they answered yes, they were asked why they recommend using extruding or expanding technology. Eleven responses were received, and 55% of those said it was to improve feed efficiency and 27% said it was to improve pelleting quality. Respondents who answered no were asked why they do not recommend using extruding or expanding processing and were allowed to check all reasons that applied; 176 responses were returned, with 45% indicating their current mill does not have extrusion/expanding technology and 23% indicating they are not familiar with extruding/expanding technologies.

Feed Additives

Participants were asked several questions to better identify the use of feed additives and their effects on feed efficiency. The first question asked individuals if they use or recommend using copper sulfate in the nursery; 69% of 134 respondents answered yes and 31% said no (Table 8). When results are sorted by demographic segments of the industry, 66% of producers (35), 84% of consultants (51), 58% of individuals in academia (24), and 54% of individuals categorized as "Other" (24) use or recommend using growth-promoting levels of copper sulfate in the nursery. Also, 68% of individuals with 10 to 20 years (31) and 80% with 20 or more years of experience recommend or use growth-promoting levels of copper sulfate, but 58% with 0 to 5 (12), and 56% with 5 to 10 (16) did not recommend or use growth-promoting levels in the nursery. A branched question asked those who answered "Yes" what percentage benefit in feed efficiency they expected from copper; those who answered "No" were asked why they did not recommend or use copper sulfate. Of the individuals who answered "Yes," 30% believed there was a 2% improvement in feed efficiency, but 20% were not sure. On the other hand, for those who answered "No," 48% were not sure why they do not use or recommend its use, and 29% said they did not recommend or use growth-promoting levels of copper sulfate because of environmental reasons.

Similarly, individuals were asked if they feed or recommend feeding growth-promoting levels of antibiotics in nursery diets. A total of 134 individuals answered, with 73% saying "Yes" and 23% saying "No" (Table 9). Demographics showed that 50% or more individuals in each industry segment or age category replied "Yes." Respondents were again asked branched questions depending on their answers. If they answered "Yes," they were asked what percentage improvement in feed efficiency they expected from its use. A total of 96 responses were received; 21% of those responded that they expected a 3% improvement, 20% responded "Not sure," 16% answered 4%, and 15% answered 5%. If survey takers answered "No," they were asked why they don't use or recommend using growth-promoting levels of antibiotics in nursery diets. Forty-two responses were returned, with 33% saying it was because the potential of development of antibiotic resistance and 26% answering "Other." The most common responses for individuals who answered "Other" were that they used antibiotics only to treat unhealthy pigs and did not feed growth-promotion levels of antibiotics.

Finally, individuals were asked if they use or recommend using Paylean in late finishing. A total of 132 answered, with 70% saying "Yes" and 30% saying "No" (Table 10). Individuals were then asked branched questions. If they said "Yes," they were asked what initial dosage they utilized; 66% of the 92 respondents answered 4.5 g/ton, and 26% answered 6.75 g/ton. They were also asked whether they utilize a step-up program or a constant level; 67% said they feed a constant level, and 33% said they use a step-up program. The step-up program was defined as feeding a lower dosage for a period of time followed by a higher dosage until pigs were marketed. If respondents said no, they were asked why they did not. Forty total responses were received, with 40% answering "Other," and 28% answering "Not sure" (Table 24). The most common reasons for individuals who replied with "Other" were that they had a niche market or special incentive not to utilize Paylean. A knowledge-based question was also asked (Table 11; Question 4) about the expected improvement in feed efficiency associated with the use of Paylean. A total of 132 participants answered the question, with 49% answering correctly (5 to 15%), 24% answering incorrectly, and 22% responding "Not sure" (Table 12; Question 4). Within respective segments of the swine industry, 30% of producers and 38% of individuals categorized as "Other" responded "Not sure" (Table 13; Question 4). Meanwhile, less than half with 5 to 10 years and 20 or more years of experience answered the question correctly (Table 14; Question 4).

Sow Efficiency

Respondents were asked approximately how much sow feed should be needed per pig weaned (Table 11; Question 5). A total of 128 individuals answered, with 51% answering correctly (70 to 100 pounds), 26% answering "Not sure," and 22% answering incorrectly (Table 12; Question 5). Although more than half of the total responses were correct, only 21% of individuals in academia (24) and 41% categorized as "Other" (22) answered correctly (Table 13; Question 5). Based on years of experience in the swine industry, only 27% with less than 5 years (11) and 43% with 5 to 10 years (14) had correct answers (Table 14; Question 5).

Thermal Environment

Individuals were also asked what feed efficiency would be for finishing pigs who initially have feed conversion rates of 2.80 if the temperature is dropped 4°F below their respective thermo-neutral zone (Table 11; Question 6). A total of 139 individuals responded; 22% answered correctly (2.88), 45% answered incorrectly, and 30% responded "Not sure" (Table 12; Question 6). Only 8% of individuals categorized as "Other" (24), 24% of consultants (51), 25% in academia, (24), and 25% of producers (40) answered correctly (Table 13; Question 6). Based on years of experience, only 33% with less than 5 years, 12% with 5 to 10 years, 9% with 10 to 20 years, and 27% with 20 or more years answered the question correctly (Table 14; Question 6).

Future Discovery for Feed Efficiency

Three discovery questions (Table 15) were asked to determine industry opinions on topic areas and their relationship to feed efficiency. When asked which topic areas would provide the largest opportunity to improve feed efficiency in the U.S. swine industry, total responses gave the top three areas as health, genetics, and feed processing (Table 16). By industry segment, producers, consultants, and those categorized as "Other" also ranked the top three areas as health, genetics, and feed processing, but academia ranked them as health, genetics, and dietary energy. Based on years of experience, participants with 0 to 5 years ranked health, feed processing, and environment; those with 5 to 10 years ranked health, genetics, and digestive tract microbiology; those with 10 to 20 years ranked health, genetics, and dietary energy; and those with 20 or more years ranked health, genetics, and feed processing as the most important topics.

Individuals were then asked to rank topic areas according to future research needs. Total responses suggest the most important areas were health, genetics, and dietary energy (Table 17). Producers ranked health, genetics, and dietary energy as the most important, but consultants and individuals categorized as "Other" ranked health, dietary energy, and digestive tract microbiology as the most important areas. Individuals in academia ranked alternative feed ingredients, amino acids, and health as the most important. By years of experience, those with 0 to 5 years ranked pelleting, dietary energy, and feed additives (other than antibiotics); those with 5 to 10 years ranked health, dietary energy, and digestive tract microbiology; and respondents with 10 to 20 years ranked dietary energy, digestive tract microbiology, and health as the most important.

The final question asked survey respondents to rank topics based on their own knowledge of the topic. Overall, individuals believed they were most knowledgeable on particle size, amino acids, and antibiotics (Tables 17 and 18). The three topic areas that individuals were the least knowledgeable in were extruding/expanding, digestive tract microbiology, and feed additives (other than antibiotics). Producers answered that they were the most knowledgeable in health, genetics, and particle size but knew the least about extruding/expanding, digestive tract microbiology, and feed additives (other than antibiotics). Consultants and those in academia answered that they were the most knowledgeable about particle size, pelleting, and amino acids but need information on extrusion/expanding, digestive tract microbiology, health, and feed additives (other than antibiotics). Participants categorized as "Other" suggested they were the most knowledgeable in antibiotics, amino acids, and dietary energy but need more information on digestive tract microbiology, health, and extrusion/expanding. Individuals with 0 to 5 years of experience believed they were most knowledgeable on alternative feed ingredients, feed additives (other than antibiotics) and health but need more information in antibiotics, extrusion/expanding, and genetics. Those with 5 to 10 years of experience answered that they were knowledgeable about amino acids, alternative feed ingredients, and particle size but need more information on extrusion/expanding, pelleting, and digestive tract microbiology. Participants with 10 to 20 years said they were most knowledgeable in amino acids, antibiotics, and dietary energy but less knowledgeable in genetics, digestive tract microbiology, and extrusion/expanding. Those with 20 or more years believed they were the most knowledgeable in particle size, pelleting, and antibiotics but needed more information on extruding/expanding, digestive tract microbiology, and feed additives (other than antibiotics).

Conclusion

Results from this survey suggest gaps in information and knowledge of feed efficiency across demographic segments of the industry. Most individuals were familiar with the advantages in feed efficiency associated with pelleting swine diets, and a large percentage of the industry utilizes or recommends using feed additives. Although knowledge of the benefits from pelleting is high, more access to affordable pellets is required to increase adoption of pelleting within the industry.

Producer responses imply that they are unfamiliar with information behind the effects of fat inclusion, particle size reduction, feed additives, and thermal environment on feed efficiency, and many were not sure which energy system to use for evaluating dietary energy.

Consultants and individuals in academia had the highest percentage of correct answers for the knowledge questions, but less than half identified the correct response when asked how reducing particle size affects feed efficiency, and very few correctly answered the question about thermal environment effects associated with feed efficiency, which suggests the need for more information and education on the two topic areas.

Respondents who classified themselves as "Other" frequently replied "Not sure" to many of the knowledge-based questions and to several production practice questions. This result may be due to the great diversity in occupation within the group.

When responses were sorted by years of experience, a majority of individuals with less experience, specifically those with 0 to 5 years, had higher percentages of "Not sure" responses, which may be related to their unfamiliarity to specific industry practices and the knowledge behind those practices.

Regardless of demographics, responses suggest that grinding cereal grains to finer particle sizes is limited mainly because of more difficult handling in feeding systems and because pelleting finishing diets is not as prevalent because it is not available in many feed mills or is not affordable. A majority of respondents believe that topics for future research and the biggest areas of opportunity to improve feed efficiency include genetics, health, feed processing, and dietary energy. Additionally, the topic areas where most of the participants were the least knowledgeable were expanding/extruding technologies, digestive tract microbiology, and feed additives (other than antibiotics).

Many individuals still define feed efficiency on a live weight basis, even though a majority of the industry market animals on a carcass weight basis; therefore, the development and implementation of tools to monitor feed efficiency on a carcass weight basis should be more clearly explained to producers and advisors. This idea can then be communicated to help individual farms and systems better recognize efficiency measurements and make decisions on specific practices to improve feed efficiency.

Extension education on current knowledge and production practices that are already proven should be expanded to provide this information in an easy-to-access format for the swine industry. Ultimately, successful dissemination will help producers and swine operations lower input costs by improving the efficiency of feed utilization.

Table 1. Demographics depicting segments of the swine industry[1,2]

Possible answers	Responses	% of total
Pork producer	57	28%
Consultant to the swine industry	67	33%
Academia	33	16%
Other[3]	48	23%
Total	205	100%

[1] The question was, "What segment of the swine industry do you represent as a primary occupation?"
[2] This question was asked in a multiple-choice format.
[3] Respondents who identified themselves as "Other" were asked to describe their role in the swine industry; a majority of those individuals recognized themselves as graduate students, related media reporters/editors, feed manufacturers, meat packers, technical support representatives for production systems, and pharmaceutical/vaccine sales representatives.

Table 2. Demographics based on years of experience in the swine industry[1,2]

Possible answers	Responses	% of total
0 to 5 years	23	12%
5 to 10 years	28	15%
10 to 20 years	40	21%
20+ years	101	53%
Total	192	100%

[1] The question was, "How many years of experience do you have working in the swine industry?"
[2] This question was asked in a multiple-choice format.

Table 3. Definition of feed efficiency as it relates to swine production[1,2]

Possible answers	Responses	% of total
Amount of feed needed for one unit of live animal weight gain	132	71%
Amount of feed needed for one unit of carcass weight gain	28	15%
Residual feed intake	9	5%
Not sure	6	3%
Other	12	6%
Total	187	100%

[1] The question was, "In your own words, please define feed efficiency with regards to swine production, or what do you use to determine feed efficiency?"
[2] This question was asked in a multiple-choice format.

Table 4. Utilization of energy systems for diet formulation[1,2]

Possible answers	Responses	% of total
Gross energy	0	0%
Digestible energy	8	6%
Metabolizable energy[3,4]	67	52%
Net energy	30	23%
Not sure[5]	21	16%
Other	3	2%
Total	129	100%

[1] The question was, "When evaluating dietary energy, what energy system do you use or recommend using?"
[2] This question was asked in a multiple-choice format.
[3] By segment, 56% of consultants (50), 54% of academia (24), and 61% of "Other" (23) answered metabolizable energy.
[4] Based on years of experience, 50% with 5 to 10 (14), 55% of 10 to 20 (29), and 54% with 20 or more years of experience answered metabolizable energy.
[5] A total of 34% of producers (32) and 58% of individuals with 0 to 5 years of experience answered "Not sure."

Table 5. Particle sizes utilized by the swine industry[1,2]

Possible answers[3]	Responses	% of total
Greater than 800 µm	1	1%
700–800 µm	13	8%
600–700 µm	49	30%
500–600 µm	39	24%
400–500 µm	24	15%
Less than 400 µm	7	4%
Not sure[4]	31	19%
Total	164	100%

[1] The question was, "What is the current particle size that you recommend or use in finishing diets?"
[2] This question was asked in a multiple-choice format.
[3] Individuals who answered with micron sizes larger than 400 µm were asked a branched question, "Why do you not grind to a finer particle size?" 35% of responses were that flowability or handling characteristics cause problems in feeding system, 18% were that ulcer rates are too high, 15% were that current mill cannot grind to a smaller particle size, and 14% were that production rate in feed mill is slowed too much.
[4] Based on demographics, 45% of individuals categorized as "Other" and 53% of individuals with 0 to 5 years of experience (17) answered "Not sure."

Table 6. Production practices on pelleting finishing diets[1,2]

Possible answers	Responses	% of total[3]
Yes	62	41%
No[4]	89	59%
Total	151	100%

[1] The question was, "Do you currently pellet, or recommend pelleting finishing diets?"
[2] This question was asked in a multiple-choice format.
[3] In total, 77% of producers (43), 55% of consultants (53), and 72% of academia answered no; 70% of individuals identified in the "Other" segment answered yes. Based on years of experience, 50% or more of each category answered no.
[4] If respondents answered no, they were asked a branched question, "Why do you not pellet finishing diets?" 29% of responses were either that it was too expensive or that pelleting capabilities were not available at their local mill. These were clearly the most common reasons why individuals do not pellet finishing diets.

Table 7. Utilization of extruding/expanding technologies[1,2]

Possible answers	Responses	% of total
Yes[3]	10	7%
No[4]	137	93%
Total	147	100%

[1] The question was, "Currently, do you use or recommend any expanding or extrusion processing in rations?"
[2] This question was asked in a multiple-choice format.
[3] Individuals who answered yes were asked a branch question, "Why do you use these technologies?" 55% of responses were to improve feed efficiency, and 27% said to improve pelleting quality.
[4] Individuals who answered no were asked a branch question, "Why do you not use these technologies? 45% of responses were that their mills did not have extrusion/expanding technology, and 23% were that they were not familiar with extrusion/expanding technology.

Table 8. Use of growth promoting levels of copper sulfate in the nursery[1,2]

Possible answers	Responses	% of total[3]
Yes[4]	93	69%
No[5]	41	31%
Total	134	100%

[1] The question was, "Currently, do you feed or recommend feeding growth promoting levels of copper sulfate in the nursery?"
[2] This question was asked in a multiple-choice format.
[3] By industry segment; 66% of producers (35), 84% of consultants (51), 58% of individuals in academia (24), and 54% of individuals categorized as "Other" (24) answered yes. Based on years of experience, 58% with 0 to 5 (12), and 56% with 5 to 10 years (16) answered no whereas, 68% with 10 to 20 (31) and 80% with 20 or more years (75) answered yes.
[4] Individuals who answered yes were asked a branch question: What benefit in feed efficiency do you expect from its inclusion in nursery diets? 30% of responses were "2%," and 20% of responses were "Not sure."
[5] Individuals who answered no were asked a branch question, "Why do you not use growth promoting level of copper sulfate in the nursery?" 48% of responses were "Not sure," and 29% were because of environmental reasons.

Table 9. Use of growth-promoting levels of antibiotics in the nursery[1,2]

Possible answers	Responses	% of total
Yes[3]	98	73%
No[4]	36	27%
Total	134	100%

[1] The question was, "Currently, do you feed or recommend feeding growth promoting levels of antibiotics in the nursery?"
[2] This question was asked in a multiple-choice format.
[3] Individuals who answered yes were asked a branch question, "What benefit in feed efficiency do you expect from its inclusion in nursery diets?" 21% responded with "3%," 20% answered "Not sure," 16% answered "4%," and 15% answered "5% or more."
[4] Individuals who answered no were asked a branch question, "Why do you not use growth promoting level of antibiotics in the nursery?" 33% of responses were to avoid development of antibiotic resistance and 26% were "Other." The most common response for individuals who answered "Other" was because they used antibiotics only to treat sick animals and not for growth promotion.

Table 10. Industry use of Paylean[1,2]

Possible answers	Responses	% of total
Yes[3,4]	92	70%
No[5]	40	30%
Total	132	100%

[1] The question was, "Currently, do you feed or recommend feeding Paylean as a growth promoter in late finishing?"
[2] This question was asked in a multiple-choice format.
[3] Individuals who answered yes were asked a branch question, "What initial level of Paylean do you utilize?" 66% responded "4.5 g/ton," and 26% answered "6.75g/ton."
[4] Individuals who answered "Yes" were asked a second branched question, "Do you utilize a step-up program or do you feed a constant level?" 67% answered that they feed or recommend feeding a constant level, and 33% fed or recommend feeding a step-up program.
[5] Individuals who answered no were asked a branch question, "Why do you not use Paylean in late finishing?" 40% of responses were "Other." The most common response for individuals who answered "Other" was because they had a niche market or special incentive not to utilize Paylean.

Table 11. Knowledge-based questions[1,2]

1	By adding 1% fat to a diet, feed efficiency is improved by approximately?
2	By decreasing particle size of a cereal grain by 100 microns, feed efficiency improves by approximately how much?
3	Although variable, feeding high quality pellets should affect feed efficiency by?
4	How much of an improvement do you expect in feed efficiency from the inclusion of Paylean?
5	In your opinion, approximately how much sow feed should be required per pig weaned?
6	If the ambient temperature of a finishing barn is at thermo-neutrality and pigs average a feed efficiency of 2.8, what is the estimated feed efficiency after the temperature drops to 4 degrees Fahrenheit below the thermo-neutral zone?

[1] All knowledge-based questions were asked in a multiple-choice format with several available responses including a "Not sure" or "Other" option.
[2] Answers considered correct by the investigators were 2%, 1.1 to 1.4%, 2 to 6%, 2.88, 70 to 100 lb, and 5 to 15% for questions 1, 2, 3, 4, 5, and 6, respectively.

Table 12. Total responses for knowledge-based questions[1]

Question	Respondents	Correct,%	Incorrect,%[2]	Not sure,%	Other,%
1	138	41	30	27	3
2	160	36	30	31	3
3	157	70	12	17	1
4	132	49	24	22	5
5	128	51	22	26	1
6	139	22	45	30	3

[1] All knowledge-based questions were asked in a multiple-choice format with several available responses, including a "Not sure" or "Other" option.
[2] Incorrect responses represent all responses received other than the correct answers, or responses of "Not sure" or "Other."

Table 13. Responses on knowledge questions based on segment of the industry[1]

	Producers			Consultants			Academia			Other[2]		
Question	Responses	Correct	Not sure	Responses	Correct	Not sure	Responses	Correct	Not sure	Responses	Correct	Not sure
1	39	31%	44%	51	63%	10%	24	33%	25%	24	17%	38%
2	44	27%	36%	57	46%	12%	28	36%	46%	31	32%	45%
3	44	70%	18%	56	80%	7%	26	62%	35%	31	52%	19%
4	33	36%	30%	51	67%	10%	24	38%	21%	24	42%	38%
5	32	50%	38%	50	70%	12%	24	21%	29%	22	41%	36%
6	40	25%	42%	51	24%	20%	24	25%	25%	24	8%	38%

[1] All knowledge-based questions were asked in a multiple-choice format with several available responses including a "Not sure" or "Other" option.
[2] Respondents who identified themselves as "Other" were asked to describe their role in the swine industry; a majority of those individuals recognized themselves as graduate students, related media reporters/editors, feed manufacturers, meat packers, technical support representatives for production systems, and pharmaceutical/vaccine sales representatives.

Table 14. Responses to knowledge questions based on years of experience[1]

	0 to 5 years			5 to 10 years			10 to 20 years			20+ years		
Question	Responses	Correct	Not sure	Responses	Correct	Not sure	Responses	Correct	Not sure	Responses	Correct	Not sure
1	12	33%	58%	17	29%	47%	32	42%	22%	77	48%	19%
2	16	25%	44%	21	48%	33%	36	39%	33%	87	34%	28%
3	16	56%	31%	20	60%	10%	36	61%	25%	85	76%	13%
4	12	50%	42%	15	40%	27%	30	53%	30%	75	49%	15%
5	11	27%	64%	14	43%	43%	29	52%	24%	74	55%	18%
6	12	33%	50%	17	12%	41%	32	9%	47%	78	27%	18%

[1] All knowledge-based questions were asked in a multiple-choice format with several available responses including a "Not sure" or "Other" option.

Table 15. Discovery questions[1]

1	Which areas provide the most opportunity for improvement in feed efficiency by the U.S. Swine Industry? (1 = important; 10 = not important)
2	Please rank the following items on the need for future research as it pertains to feed efficiency. (1 = important; 10 = not important)
3	Please rank your level of knowledge on the following areas as they pertain to feed efficiency. (1 = knowledgeable; 10 = need more education)

[1] Discovery questions were asked in a ranking format where topics areas were provided and individuals were asked to rank the topics on a numerical scale from 1 to 10 based on the priority.

Table 16. Priority rankings by demographic segments for discovery question 1[1]

	Total	Industry segment				Years of experience			
Topic	responses	Producers	Consultants	Academia	Other	0 to5	5 to 10	10 to 20	20+
Alternative feed ingredients	8.1	8.1	8.0	7.6	8.7	6.4	9.2	7.6	8.2
Amino acids	6.2	6.2	6.6	5.4	6.2	8.1	7.1	5.6	6.0
Antibiotics	7.7	8.3	7.4	7.5	7.9	7.0	8.0	7.8	7.7
Dietary energy	4.6	4.3	4.4	4.9	5.4	5.1	5.3	4.3	4.6
Digestive tract microbiology/health	5.5	6.1	5.4	5.5	4.8	5.6	3.9	5.4	5.8
Environment	5.5	5.4	5.9	5.3	5.0	4.6	5.6	6.0	5.4
Feed additives (other than antibiotics)	6.9	7.1	6.9	7.0	6.3	6.3	5.1	7.0	7.3
Feed processing	4.3	4.0	4.1	5.2	4.5	4.0	4.4	4.8	4.2
Genetics	3.7	2.8	4.0	4.2	3.7	5.1	3.8	3.0	3.7
Health	2.2	2.3	2.2	2.1	2.2	2.8	2.6	2.7	1.9

[1] Important = 1; not important = 10.

Table 17. Priority rankings by demographic segments for discovery question 2[1]

Topic	Total responses	Industry segment: Producers	Consultants	Academia	Other	Years of experience: 0 to 5	5 to 10	10 to 20	20+
Alternative feed ingredients	4.1	4.3	4.4	4.0	3.2	3.9	4.1	4.3	4.1
Amino acids	4.1	4.3	4.4	3.7	3.3	3.3	3.6	4.2	4.2
Antibiotics	5.9	6.0	5.9	6.3	5.2	5.5	5.6	6.1	5.9
Dietary energy	3.7	3.7	3.8	4.1	2.8	2.9	3.2	3.8	3.8
Digestive tract microbiology/health	3.9	4.2	3.9	4.6	2.2	3.8	2.7	3.9	4.1
Environment	4.4	4.5	4.7	5.0	3.0	3.8	4.0	4.8	4.4
Feed additives (other than antibiotics)	4.2	4.2	4.6	4.4	3.1	2.9	3.2	4.8	4.4
Feed processing (expanding/extrusion)	4.7	5.1	5.0	5.0	3.2	4.3	3.6	5.1	4.9
Feed processing (particle size)	4.2	4.4	4.2	4.7	3.6	4.0	3.3	4.9	4.2
Feed processing (pelleting)	4.3	5.1	4.2	4.6	3.1	2.8	3.7	4.9	4.4
Genetics	3.6	2.9	4.1	4.7	2.2	3.5	2.5	4.1	3.7
Health	3.2	3.0	3.5	4.1	1.8	3.4	2.5	4.0	3.0

[1] Important = 1; not important = 10.

Table 18. Priority rankings by demographic segments for discovery question 3[1]

Topic	Total responses	Industry segment: Producers	Consultants	Academia	Other	Years of experience: 0 to 5	5 to 10	10 to 20	20+
Alternative feed ingredients	5.1	5.4	4.7	5.4	5.4	5.5	4.4	5.3	5.1
Amino acids	4.8	5.8	4.4	4.9	4.5	6.5	3.9	4.8	4.9
Antibiotics	5.0	5.6	4.7	5.3	4.3	7.4	5.4	5.2	4.6
Dietary energy	5.1	5.3	5.0	5.3	4.9	6.5	4.6	5.3	5.0
Digestive tract microbiology/health	6.0	6.2	5.7	6.5	5.7	7.0	6.0	5.8	6.0
Environment	5.1	5.0	5.1	5.2	5.2	6.0	5.0	5.3	5.0
Feed additives (other than antibiotics)	5.7	6.4	5.2	6.3	5.4	5.5	4.9	5.8	5.9
Feed processing (expanding/extrusion)	6.6	7.0	6.6	6.7	6.1	7.3	6.8	7.1	6.4
Feed processing (particle size)	4.7	4.9	4.3	4.8	5.2	5.8	4.4	5.7	4.2
Feed processing (pelleting)	5.1	6.1	4.5	5.0	5.2	5.8	5.7	5.7	4.7
Genetics	5.2	4.9	5.3	5.0	5.8	7.1	5.3	5.9	4.8
Health	5.3	4.8	5.4	5.8	5.0	5.6	5.1	5.8	5.1

[1] Knowledgeable = 1; need more information = 10.

Effects of Dietary Vitamin E Level and Source on Sow, Milk, and Piglet Concentrations of α-tocopherol[1]

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Summary
A total of 126 gilts and sows (PIC 1050) and their litters were used to determine the effect of dietary vitamin E level and source on sow plasma, milk, and piglet tissue concentrations of α-tocopherol. The 6 dietary treatments included 2 levels of dl-α-tocopherol acetate (Syn E) at 44 and 66 mg/kg (40,000 and 60,000 mg/ton) and 4 levels of d-α-tocopherol acetate (Nat E) at 11, 22, 33, and 44 mg/kg (10,000, 20,000, 30,000 and 40,000 mg/ton). From breeding through d 69 of gestation, sows were fed 4.5 lb/d of a diet containing 40% dried distillers grains with solubles (DDGS), 0.30 ppm added Se, and no added vitamin E. Vitamin E treatments were fed from d 70 of gestation through weaning (d 21). Plasma was collected from sows on d 69 and 100 of gestation, at farrowing, and at weaning. Colostrum (d 1) and milk samples (weaning) were also collected. Plasma from 3 pigs per litter and heart and liver samples from 1 pig per litter were collected at weaning. All plasma, milk, and tissue samples from 6 sows and litters per treatment were analyzed for α-tocopherol.

Although tissue, plasma, and milk concentrations of α-tocopherol were the primary response criteria of interest, sow and litter performance were also measured. As expected, treatment effects were not observed ($P > 0.10$) for lactation feed intake, sow BW, or backfat thickness measurements. A trend ($P < 0.09$) for decreased average weaning weight in litters of sows fed 44 mg/kg Syn E was observed, likely because of the difference ($P < 0.05$) in weaning age and the numerical differences in birth weight. No other differences in litter performance were observed ($P > 0.05$).

As dietary Nat E increased, sow plasma, colostrum, milk, piglet plasma, and piglet heart concentrations of α-tocopherol increased (linear; $P < 0.03$). Sows fed diets with 44 mg/kg Nat E had greater ($P < 0.02$) plasma, colostrum, and piglet plasma concentrations of α-tocopherol than sows fed the 44 mg/kg of Syn E. Sows fed 66 mg/kg Syn E also had greater ($P < 0.03$) plasma concentrations of α-tocopherol at weaning than sows fed 44 mg/kg Syn E. Regression analysis indicated that the bioavailability coefficients for Nat E relative to Syn E ranged from 2.1 to 4.2 for sow and piglet plasma α-tocopherol, 2.9 to 3.0 for colostrum α-tocopherol, 1.6 to 7.3 for milk α-tocopherol, and 1.8 to 7.5 for heart and liver α-tocopherol. Overall, this study indicates that the relative bioavailability of Nat E relative to Syn E varies depending on the response criteria, but that it is greater than the standard value of 1.36 in sows.

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Key words: α-tocopherol, bioavailability, natural vitamin E, sow

Introduction

Vitamin E is a generic term for a group of tocopherols and tocotrienols that serve as antioxidants in the lipid components of animal and plant tissues. Of the 8 compounds (4 tocopherols and 4 tocotrienols), α-tocopherol is the most bioactive form for animals. Within the α-tocopherol isomer are eight stereoisomers that position three methyl groups at the 2>, 4>, and 8> positions of the phytyl tail (R or S configuration) differently. The biological activities of these 8 stereoisomers range from 21 to 100%, with the RRR-α-tocopherol form being the greatest.

Two sources of vitamin E are available for supplementing swine diets. Synthetic vitamin E (all rac-α-tocopherol, dl-α-tocopherol) is a combination of the 8 stereoisomers, whereas natural vitamin E (RRR-α-tocopherol, d-α-tocopherol) comprises only the RRR stereoisomer. Using an esterified form to either acetate or succinate is common to prevent oxidation until the acetate or succinate is removed. Harris and Ludwig (1949[5]) showed that the relative bioavailability of natural vitamin E was 1.36 times that of synthetic vitamin E in pregnant rats, and that value has been extrapolated for use in other species. Recent research by Mahan et al. (2000[6]) suggests the ratio of relative bioavailability for natural vitamin E to synthetic vitamin E is 1.54 or greater in sows based on α-tocopherol concentrations in milk.

Most of the work with vitamin E has been with corn-soybean meal diets without DDGS. Adding DDGS to sow diets can reduce cost and improve profitability but increases the potential for oxidative compounds in the diets. Testing increasing natural vitamin E and comparing it to standard synthetic vitamin E levels in diets with high levels of DDGS could yield an estimate for the relative bioavailability of the two different sources; therefore, the objectives of this study were to determine the level of α-tocopherol in plasma, milk, and piglet body tissues when supplied from synthetic or natural vitamin E and to estimate the bioavailability of natural vitamin E relative to synthetic vitamin E when included in diets with DDGS.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Facility in Manhattan, KS.

A total of 126 gilts and sows (PIC 1050) and their litters were used to evaluate the effects of dietary vitamin E level and source on sow and piglet concentrations of α-tocopherol. The six dietary treatments were 2 levels of dl-α-tocopherol acetate (Syn E) at 44 and 66 mg/kg (40,000 and 60,000 mg/ton) and 4 levels of d-α-tocopherol acetate (Nat E) at 11, 22, 33, and 44 mg/kg (10,000, 20,000, 30,000, and 40,000 mg/ton). Treatments were allotted to sows in a generalized block design with farrowing group as

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[5] Harris, P. L., and M. I. Ludwig. 1949. Relative vitamin E potency of natural and synthetic alpha-tocopherol. J. Biol. Chem. 179:1111–1115.

[6] Mahan, D. C., Y. Y. Kim, and R. L. Stuart. 2000. Effects of vitamin E sources (RRR- or all rac-alpha-tocopherol acetate) and levels on sow reproductive performance, serum, tissue, and milk alpha tocopherol contents over a five parity period, and effects on progeny. J. Anim. Sci. 78:110–119.

the blocking factor. Six farrowing groups (farrowed between November 2010 and May 2011) were used to obtain the 126 gilts and sows for the trial.

Before beginning the experiment, all gilts and sows were fed diets containing 66 mg/kg Syn E. From breeding through d 69 of gestation, gilts and sows were fed 4.5 lb of a gestation diet containing no added vitamin E. On d 70 of gestation, gilts and sows were allotted to their dietary treatment and remained on their assigned dietary vitamin level and source through the end of lactation. The gestation and lactation diets were formulated at 0.55% and 0.94% standardized ileal digestible lysine, respectively (Table 1). Gestation and lactation diets contained 40% and 20% DDGS, respectively. A sample of each DDGS batch was analyzed for sulfur content with calcium sulfate then added to maintain a constant sulfur level of 0.80 ppm in the DDGS. All diets were also formulated with 0.30 ppm added selenium from sodium selenite provided in the trace mineral premix. For the first 3 d after farrowing, sows were gradually provided increased feed according to appetite; after d 3, all sows were allowed ad libitum access to the lactation diet. Temperature in the farrowing facility was maintained at a minimum of 68°F, and supplemental heat was provided to the piglets with heat lamps.

Although not the primary response criteria for the experiment, sow BW and backfat thickness measurements were recorded at breeding, d 69 of gestation, postfarrowing, and at weaning. Individual piglet weight, piglet count, and total litter weight were recorded at birth, d 3 of lactation, d 17 of lactation, and at weaning. Lactation feed intake was also measured. The primary response criteria were sow plasma, piglet tissue, and milk α-tocopherol levels. Blood was collected via jugular venapuncture on d 69 and 100 of gestation, approximately 4 h after feeding. Blood was stored on ice for approximately 1 h, then centrifuged at 1,600 × g for 20 min. Milk and sow plasma samples were also collected at 8 to 12 h postfarrowing and at weaning. Milk samples were obtained by an intravenous injection of oxytocin and milk was collected from all functional glands. At weaning, plasma was taken from 3 pigs per litter, and 1 pig per litter was sacrificed to obtain heart and liver samples, which were immediately flash frozen in liquid nitrogen to limit oxidation.

From each farrowing group, samples from 1 sow and litter per dietary treatment were used to analyze α-tocopherol, and similar parties were selected for each dietary treatment within a farrowing group. Samples were analyzed for α-tocopherol by HPLC at Dr. Mahan's laboratory at The Ohio State University.

Experimental data were analyzed initially using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Overall treatment significance was first determined by the overall treatment F-test. Contrast statements were used to test for linear and quadratic effects associated with increasing Nat E and to compare the 44 mg/kg Syn E treatment separately with the 44 mg/kg Nat E and 66 mg/kg Syn E treatments. Farrowing group was used as a random effect and sow was used as the experimental unit for all data analysis. For sow performance, interactions between dietary treatments and farrowing group were non-significant and were pooled with error variance components for each response. For sow plasma, d 69 plasma α-tocopherol was used as a covariate. Statistics were considered significant at $P < 0.05$ and were considered tendencies at $0.05 < P < 0.10$.

Coefficients for the bioavailability of Nat E relative to Syn E were also calculated. Linear regression was first conducted utilizing the PROC REG procedure of SAS (SAS Institute, Inc., Cary, NC) to relate the analyzed plasma, milk, and tissue levels of α-tocopherol to the dietary level of Nat E. Based on the regression line, the Nat E dietary level needed to achieve the same tissue concentration of α-tocopherol as each of the Syn E treatments was calculated. The ratio of each dietary Syn E relative to the calculated Nat E was used to estimate the relative bioavailability.

Results and Discussion

The analyzed concentrations of α-tocopherol in each treatment's gestation and lactation diet are shown in Table 2. Although not measured, the amount of indigenous α-tocopherol is approximately 10 to 12 mg/kg above any added. The analyzed α-tocopherol values were similar to those expected with the exception of the lactation diet with 66 mg/kg Syn E, gestation diet with 44 mg/kg Nat E, and lactation diet with 44 mg/kg Nat E, which were at lower than expected values.

No differences were observed ($P > 0.10$) in sow BW or backfat thickness measurements at any of the time points (Table 3) or in total or daily lactation feed intake ($P > 0.10$). Total number, average weight, and total litter weight differences were not observed ($P > 0.10$) for total born, born alive, d 3 of lactation, or d 17 of lactation (Table 4). A trend was observed ($P = 0.09$) for a difference in average pig weight at weaning, primarily due to the numerically lower average piglet weight for sows on the 44 mg/kg Syn E diet compared with other levels and/or sources of vitamin E. This lower average weight may be due to the difference ($P = 0.05$) in weaning age and a numerically lower average piglet birth weight for sows on that particular treatment. Differences in sow performance were not expected in this trial. When comparing 2 levels and 2 sources of vitamin E over 5 parities, Mahan et al. (2000) observed no differences ($P > 0.05$) in lactation litter performance. Also, the main goal of the experiment was not to determine differences in litter performance, so insufficient numbers of sows were used per treatment to determine differences in litter performance.

Sow plasma α-tocopherol increased (linear; $P < 0.003$) with additional added Nat E on d 100 of gestation, postfarrowing, and at weaning (Table 5). Sow plasma α-tocopherol was greater ($P < 0.003$) for sows fed 44 mg/kg Nat E than for sows fed Syn E at each time point. Sow plasma α-tocopherol also increased ($P < 0.03$) at weaning with increasing dietary Syn E. Figure 1 shows plasma α-tocopherol concentrations on d 100 of gestation in relation to the dietary level and source of vitamin E. The figure also illustrates the calculated bioavailability estimates of 2.1 and 2.4 for the 44 and 66 mg/kg Syn E treatments, respectively. These results suggest that Nat E has approximately 2.1 to 2.4 times the activity of Syn E or that when formulated on a mg/kg basis, Nat E can be added at 41.6% to 47.6% the level of Syn E and obtain the same tissue levels of α-tocopherol (Table 6). Plasma α-tocopherol post farrowing yielded bioavailability estimates of 4.2 and 3.0 for the 44 and 66 mg/kg Syn E treatments, respectively. Estimates of bioavailability based on sow plasma α-tocopherol at weaning were 2.7 and 2.4 for the 44 and 66 mg/kg Syn E treatments, respectively.

Sow colostrum and milk α-tocopherol increased (linear; $P < 0.03$) with increasing dietary Nat E. Sows fed 44 mg/kg Nat E had greater ($P < 0.05$) colostrum α-tocopherol than sows fed 44 mg/kg Syn E. A numerical increase in colostrum α-tocopherol occurred as Syn E increased in the sow's diet, but the difference was not significant ($P > 0.05$) due to a large amount of variation in α-tocopherol levels in colostrum. The calculated bioavailability estimates based on colostrum α-tocopherol were 3.0 and 2.9 for the 44 and 66 mg/kg Syn E treatments, respectively. Also, the estimates for bioavailability based on milk α-tocopherol were 1.6 and 7.3 for the 44 and 66 mg/kg Syn E treatments, respectively. The dramatic difference in the two estimates is due to the numerical decrease in milk α-tocopherol concentration as Syn E increased in the diet, which suggests that the response to Syn E was no longer in the linear portion and may have plateaued. The estimate for milk α-tocopherol concentrations was similar to the 1.54 estimate by Mahan et al. (2000).

Heart and plasma α-tocopherol increased (linear: $P < 0.004$) in piglets as the Nat E increased in the sow's diet, and the levels tended to increase (linear; $P = 0.09$) in the piglet's liver. Pigs from sows fed 44 mg/kg Nat E had greater ($P < 0.05$) plasma α-tocopherol than pigs from sows fed 44 mg/kg Syn E. Similar to sow's milk, a numerical decrease in plasma, heart, and liver α-tocopherol was observed as Syn E increased in the sow's diet, but the differences were not significant ($P > 0.05$). Based on analyzed piglet α-tocopherol concentrations of 44 and 66 mg/kg Syn E levels, respectively, the estimates for bioavailability were 3.0 and 5.1 for plasma, 1.8 and 5.3 for heart, and 2.0 and 7.5 for liver. As with sow's milk, the 66 mg/kg Syn E Ac treatment appears to no longer be in the linear portion of the response.

Several additional studies have compared the bioavailability or potency of Nat E and Syn E in sows. Lauridsen et al. (2002[7]) utilized deuterated labeled forms of Nat E and Syn E to compare the bioavailability of the two sources by supplementing both simultaneously. They determined ratios of incorporation of 2:1 for Nat E compared to Syn E in sow's milk and plasma, which also related to a 2:1 ratio in suckling piglet plasma and tissues. One explanation for the difference as compared to the rat fetal absorption model is related to the presence of the α-tocopherol transport protein (TTP), which was first thought to be associated only with hepatic regulation of plasma α-tocopherol concentrations. The TTP preferentially binds and facilitates the transport of the 2-R-sterioisomers of α-tocopherol, which agrees with the 2:1 bioavailability observed by Lauridsen et al.. Some evidence, however, indicates that this transfer protein, which is expressed in uterine tissues of mice, will transport the 2-S-sterioisomers when concentrations of vitamin E are very low. The rat fetal absorption model used low levels of vitamin E, which may explain the lower estimate of bioavailability observed in this experiment and by other researchers.

A range of bioavailability estimates was calculated in this trial. The bioavailability coefficients for Nat E relative to Syn E ranged from 2.1 to 4.2 for sow and piglet plasma α-tocopherol, 2.9 to 3.0 for colostrum α-tocopherol, 1.6 to 7.3 for milk α-tocopherol, and 1.8 to 7.5 for heart and liver α-tocopherol. This study shows that the bioavailability for Nat E relative to Syn E varies depending on the response criteria but is greater than the standard value of 1.36 in sows.

[7] Lauridsen, C., H. Engel, S. K. Jensen, and A. M. Craig. 2002. Lactating sows and suckling piglets preferentially incorporate RRR- over all-rac-α-tocopherol into milk, plasma, and tissues. J. Nutr. 132:1258–1264.

Table 1. Composition of diets (as-fed basis)[1]

Item	Gestation	Lactation
Ingredient, %		
Corn	51.98	51.96
Soybean meal (46.5% CP)	4.15	24.24
DDGS[2,3]	40.00	20.00
Monocalcium P (21% P)	0.70	1.00
Limestone	1.75	1.45
Salt	0.50	0.50
Vitamin premix[4]	0.25	0.25
Trace mineral premix	0.15	0.15
L-lysine HCl	0.18	0.10
Phytase[5]	0.10	0.10
Vitamin E premix[6]	0.25	0.25
Total	100	100
Calculated analysis		
ME, kcal/lb	1,498	1,494
CP, %	17.4	21.2
Total lysine, %	0.71	1.10
SID[7] amino acids, %		
Lysine	0.55	0.94
Threonine	0.49	0.66
Methionine	0.28	0.32
Tryptophan	0.11	0.20
Isoleucine	0.51	0.74
Leucine	1.67	1.79
Ca, %	0.84	0.84
P, %	0.61	0.66
Available P, %[8]	0.50	0.49

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol.
[2] DDGS: dried distillers grains with solubles.
[3] Calcium sulfate was added at the expense DDGS to maintain 0.60% S within each batch of DDGS.
[4] The vitamin premix contained normal KSU levels of vitamins with the exception of no vitamin E.
[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 272 FTU/lb of diet.
[6] Vitamin E premixes were generated for each treatment by combining appropriate amounts of synthetic or natural vitamin E and rice hulls. For the depletion diet used in gestation, the vitamin E premix was replaced with corn starch.
[7] SID: standardized ileal digestible.
[8] Phytase provided 0.11% available P to the gestation and lactation diets.

Table 2. Analyzed dietary concentration of α-tocopherol, mg/kg[1]

Source of vitamin E:	Synthetic		Natural			
Added vitamin E, mg/kg:	44	66	11	22	33	44
Gestation diet	54.4	85.7	23.0	33.4	46.0	45.7
Lactation diet	54.9	66.3	23.0	33.2	47.6	48.4

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol. Diets samples were taken from each batch of feed, then one composite sample from each treatment was used for analysis.

Table 3. Effects of vitamin E level and source on sow backfat, BW, and lactation feed intake[1]

								Significance level, $P<$		
Source of vitamin E:	Synthetic		Natural						Nat. vitamin E	
Added vitamin E, mg/kg:	44	66	11	22	33	44	SEM	Trt	Linear	Quadratic
n	21	21	21	21	21	21				
Backfat measurements, mm[2]										
Breeding[3]	15.7	16.0	16.0	16.0	15.6	15.9	0.70	0.99	0.84	0.80
Gestation d 69[4]	16.2	16.4	16.2	16.0	15.9	16.3	0.76	0.99	0.96	0.72
Postfarrowing	15.8	15.7	15.6	15.9	15.7	16	0.59	0.99	0.69	0.94
Weaning	12.5	12.3	12.4	12	11.9	13	0.57	0.78	0.47	0.20
Sow BW, lb										
Breeding[3]	413	399	423	417	417	424	16.9	0.86	0.96	0.7.0
Gestation d 69[4]	457	449	462	455	460	467	15.9	0.93	0.71	0.57
Postfarrowing	469	459	480	470	472	476	14.9	0.89	0.86	0.57
Weaning	454	446	463	451	449	461	15.0	0.93	0.87	0.36
Daily lactation feed intake, lb										
d 0 to 17	13.4	13.2	13.1	13.0	12.8	13.0	0.74	0.98	0.89	0.78
d 0 to weaning	13.7	13.5	13.3	13.3	13.0	13.5	0.74	0.98	0.93	0.62

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol.
[2] Backfat measurements were determined by averaging both sides at the last rib, approximately 4 in. off the midline.
[3] From breeding until d 70 of gestation, all sows were fed a deficient diet containing no supplemental vitamin E.
[4] On d 70, sows were allotted to treatment diets and sows remained on the same vitamin E level throughout the remainder of gestation and through lactation.

Table 4. Effects of vitamin E level and source on sow lactation performance[1]

								Significance level, *P*<		
Source of vitamin E:	Synthetic		Natural						Nat. vitamin E	
Added vitamin E, mg/kg:	44	66	11	22	33	44	SEM	Trt	Linear	Quadratic
n	21	21	21	21	21	21				
Litter size, n										
Total born	14.1	13.2	12.6	12.6	13.2	14.0	0.82	0.65	0.18	0.61
Born alive	13.7	13.0	12.0	12.0	12.8	13.2	0.81	0.66	0.24	0.80
d 3	11.7	11.8	11.4	11.4	12.0	11.9	0.35	0.49	0.09	0.75
d 17	11.5	11.3	11.0	10.9	11.3	11.1	0.34	0.75	0.57	0.79
Weaning	11.5	11.3	11.0	10.8	11.3	11.1	0.34	0.66	0.46	0.92
Total litter weight, lb										
Total born	41.0	43.1	37.6	38.7	39.4	42.0	2.14	0.47	0.16	0.73
Born alive	40.4	42.2	36.4	37.5	38.5	40.2	2.13	0.43	0.21	0.90
d 3	45.7	49.7	46.0	46.5	47.4	47.1	1.71	0.54	0.57	0.81
d 17	123.0	129.3	126.4	126.6	125.0	128.8	5.29	0.96	0.80	0.72
Weaning	132.5	145.9	138.1	138	143.0	144.5	5.78	0.53	0.33	0.89
Average piglet weight, lb										
Total born	2.93	3.36	3.11	3.20	3.06	3.09	0.116	0.17	0.69	0.79
Born alive	2.96	3.37	3.16	3.24	3.08	3.13	0.117	0.23	0.64	0.93
d 3	3.88	4.21	4.05	4.08	3.94	3.95	0.124	0.38	0.40	0.96
d 17	10.74	11.45	11.66	11.62	10.99	11.60	0.417	0.31	0.62	0.35
Weaning	11.56	12.93	12.68	12.82	12.61	12.98	0.459	0.09	0.68	0.76
Lactation length, d	19.1	20.0	19.2	19.5	20.0	20.2	0.31	0.05	0.01	0.82

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol.

Table 5. Effects of vitamin E level and source on sow plasma, milk and piglet tissue concentrations of α-tocopherol[1]

								Significance level, *P*<				
Source of vitamin E:	Synthetic		Natural						Nat. vitamin E		44 Syn E vs.	
Added vitamin E, mg/kg:	44	66	11	22	33	44	SEM	Trt	Linear	Quadratic	44 Nat	66 Syn.
n	6	6	6	6	6	6						
Tissue concentrations of α-tocopherol, µg/mL												
Sow plasma												
Gestation day 69[2]	1.00	0.85	0.89	0.89	0.95	0.98	0.082	0.73	0.39	0.85	0.83	0.18
Gestation day 100[3]	1.32	1.51	1.09	1.28	1.64	1.99	0.187	0.003	0.001	0.56	0.003	0.38
Farrowing[3]	0.72	0.87	0.75	0.86	1.01	1.19	0.12	0.02	0.003	0.72	0.002	0.29
Weaning[3]	1.41	1.88	1.15	1.75	2.02	2.53	0.139	0.001	0.001	0.74	0.001	0.03
Sow colostrum[4]	8.19	10.31	7.62	11.39	9.40	17.76	2.165	0.02	0.004	0.26	0.003	0.46
Sow milk[5]	3.25	2.51	2.36	3.22	3.75	3.63	0.458	0.15	0.03	0.26	0.53	0.24
Piglet levels[5]												
Plasma	2.47	2.38	2.11	3.03	3.51	3.78	0.376	0.03	0.004	0.40	0.02	0.69
Heart	4.84	3.93	3.60	4.75	5.93	6.00	0.619	0.02	0.002	0.31	0.13	0.23
Liver	4.18	3.39	2.99	4.88	4.96	5.12	1.063	0.34	0.09	0.31	0.43	0.50

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol.
[2] Prior to beginning dietary treatments.
[3] Adjusted with d 69 as a covariate.
[4] Collected 8 to 12 hours after the completion of farrowing.
[5] Collected at the time of weaning.

Table 6. Bioavailability estimates based on tissue concentrations of α-tocopherol[1]

	Calculated bioavailability of Nat E relative to Syn E[2]	
Synthetic vitamin E, mg/kg:	44	66
Sow plasma		
Gestation d 100	2.1	2.4
Farrowing	4.2	3.0
Weaning	2.7	2.4
Sow colostrum	3.0	2.9
Sow milk	1.6	7.3
Piglet levels		
Plasma	3.0	5.1
Heart	1.8	5.3
Liver	2.0	7.5

[1] A total of 126 sows and litters were used over 6 farrowing groups to determine the effects of supplemental vitamin E level and source on sow, milk, and piglet levels of α-tocopherol.
[2] The relative bioavailability of natural vitamin E was calculated for each level of synthetic vitamin E.

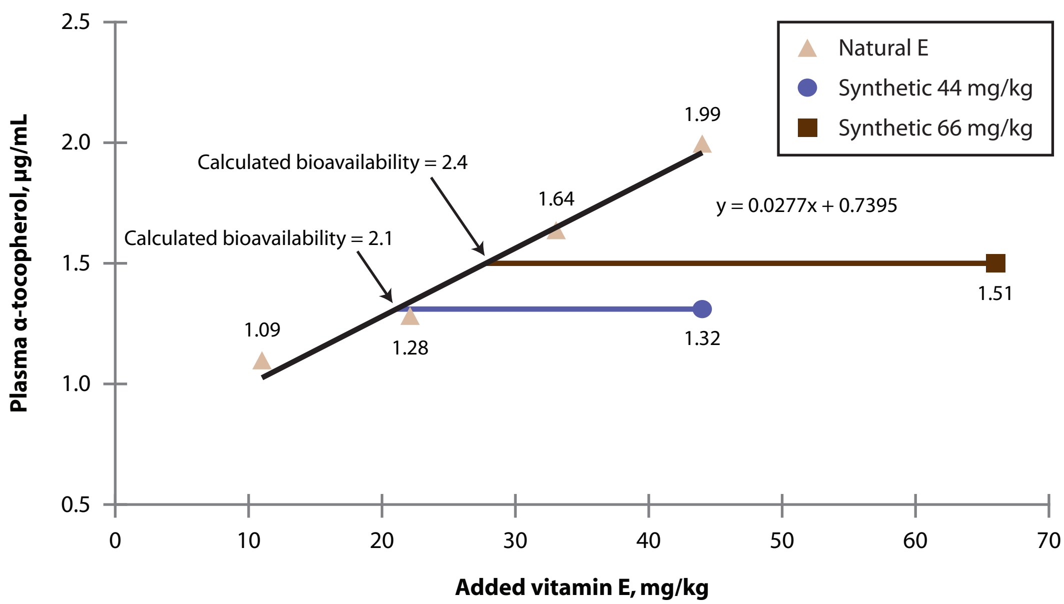

Figure 1. The graph depicts the response in sow plasma α-tocopherol from four levels of Nat E and 2 levels of Syn E on d 100 of gestation. Bioavailability of natural vitamin E relative to synthetic vitamin E was also calculated based on the α-tocopherol response from the regression line for natural E against each level of synthetic vitamin E. For example, the regression line predicts that 21 mg/kg of Nat E would need to add to achieve the same plasma α-tocopherol as 44 mg/kg Syn E, and the ratio of the two inclusion rates gives us the 2.1 estimate for bioavailability.

The Effects of Corn- or Sorghum-Based Diets with or without Sorghum Dried Distillers Grains with Solubles on Lactating Sow and Litter Performance

K. M. Sotak, R. D. Goodband, M. D. Tokach, S. S. Dritz[1], J. M. DeRouchey, and J .L. Nelssen

Summary

A total of 140 sows (PIC 1050) and their litters were used to determine the effects of corn- or sorghum-based diets with or without 20% sorghum dried distillers grains with solubles (DDGS) on lactating sow and litter performance. On d 110 of gestation, sows were allotted to 1 of 4 dietary treatments arranged in a 2 × 2 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0 vs. 20%; 32.1% CP and 9.2% crude fat as-fed). All diets were formulated to 0.97% standardized ileal digestible lysine but were not balanced for energy. Litters were equalized to at least 12 pigs per sow after farrowing. Two sows and one sow were removed from the study for the sorghum and sorghum-DDGS treatments, respectively, because of initial feed refusal.

Overall (d 0 to 21), a tendency ($P < 0.08$) for a DDGS × grain source interaction was observed as ADFI increased in corn-based diets when DDGS were added, but this tendency decreased in sorghum-based diets. Sows fed the sorghum-based diets had decreased ($P < 0.04$) lactation BW loss compared with those fed corn-based diets. Litter weaning weights tended to be lower ($P < 0.06$) for sows fed the diets containing DDGS compared with those fed the diets without DDGS. Sows fed the sorghum-based diet with 20% sorghum DDGS had the lightest litter weaning weight at 155 lb, with weaning weights averaging 161 to 162 lb for the other dietary treatments. Following this trend, litter weight gain tended ($P < 0.09$) to decrease when sorghum DDGS were added to corn- or sorghum-based diets. No differences were observed in piglet survivability among dietary treatments. Overall, feeding sows corn- vs. sorghum-based diets (without DDGS) in lactation did not affect litter performance; however, the 5% decrease in litter weaning weight of sows fed sorghum with 20% sorghum DDGS needs to be taken into account when selecting ingredients for lactating sows.

Key words: lactation, sorghum, sorghum DDGS, sow

Introduction

Sorghum grain is grown in the Great Plains region of the United States due to its resilience in drought conditions. Sorghum DDGS are often available to swine producers due to the large acreage of sorghum in the area and its use in ethanol production.

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Grain sorghum is a suitable replacement for corn in nursery and finishing diets (Sotak et al., 2011[2]; Benz et al., 2011[3]). Previous research has found that gestating sow performance is not affected by corn DDGS inclusion rates from 40 to 80% (Monegue and Cromwell, 1995[4]) and that lactating sow performance is not affected by corn DDGS at an inclusion rate of 30% (Greiner et al., 2008[5]). Louis et al. (1991[6]) observed no differences for lactation weight loss among sows fed corn- or sorghum-based diets; however, a reduction in litter weaning weights was observed for sows fed the sorghum-based diet.

Research has been conducted on lactating sows fed corn DDGS, but more research needs to be conducted to determine the feeding value of grain sorghum and sorghum DDGS for lactating sows.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved all practices and procedures used in these experiments. This study was conducted at the K-State Swine Teaching and Research Center in Manhattan. The facility is a totally enclosed, environmentally controlled, mechanically ventilated barn. The barn contains 29 farrowing crates that are each equipped with a single feeder and nipple waterer.

The sorghum, corn, and sorghum DDGS were analyzed for DM, CP, crude fat, crude fiber, and ash at the K-State Analytical Laboratory (Manhattan, KS). Standard ileal digestibility values for the sorghum DDGS were derived from Urriola et al. (2009[7]) and used in diet formulation (Table 1). The sorghum grain used in this study was a red pericarp variety, and the corn grain used was #2 yellow dent. The corn DDGS used were golden brown, and the sorghum DDGS were slightly darker than the corn DDGS in visual color.

A total of 140 sows (PIC 1050) and their litters were used. Sows were randomly allotted to 1 of 4 experimental diets throughout 5 farrowing groups using farrowing group as the blocking criteria. Each farrowing group had 7 sows per treatment with 4 replications. During gestation, all sows were fed a corn-based diet with 20% corn DDGS. Feed amounts in gestation were assigned based on sow body condition.

Treatments were arranged in a 2 × 2 factorial with main effects of grain source (corn vs. sorghum) and sorghum DDGS (0 vs. 20%; Table 2). Sows had ad libitum access to water throughout the study. Sows were switched to their experimental diets on d 110 of gestation, corresponding to their move to the farrowing house. Sows had restricted

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[2] Sotak et al., Swine Day 2011, Report of Progress 1056, pp. 118–128.

[3] Benz, J. M., M. D. Tokach, S. S. Dritz, J. L. Nelssen, J. M. DeRouchey, R. C. Sulabo, and R. D. Goodband. 2011. Effects of increasing choice white grease in corn- and sorghum-based diets on growth performance, carcass characteristics, and fat quality characteristics of finishing pigs. J. Anim. Sci. 89:773–782.

[4] Monegue, J. J., and G. L. Cromwell. 1995. High dietary levels of corn by-products for gestating sows. J. Anim. Sci. 73(Suppl. 1):86(Abstr.).

[5] Greiner, L. L., X. Wang, G. Allee, and J. Conner. 2008. The feeding of dry distillers grains with solubles to lactating sows. J. Anim. Sci. 86(Suppl. 2):63 (Abstr.).

[6] Louis, G. F., A. J. Lewis, and E. R. Peo Jr. 1991. Feeding value of grain sorghum for the lactating sow. J. Anim. Sci. 69:223–229.

[7] Urriola, P. E., D. Hoehler, C. Pederson, H. H. Stein, and G. C. Shurson. 2009. Amino acid digestibility of distillers dried grains with solubles produced from sorghum- and sorghum-corn blend, and corn fed to pigs. J. Anim. Sci. 87:2574–2580.

access to feed from d 110 until farrowing (4.5 lb). Sows were fed 6.0, 8.0, and 12.0 lb on d 0 of farrowing and subsequent 2 d, respectively. Sows had ad libitum access to feed for the remainder of the lactation period.

Average daily feed intake was determined by measuring total feed disappearance to d 0, 7, 14, and 21 (weaning). Sow weights were measured as the sows were placed in the farrowing house on d 110 of gestation, within 24 h postfarrowing, and at weaning.

After birth, pigs were weighed and processed, then distributed among treatments with at least 12 pigs per sow. Mummified and stillborn pigs were also recorded to calculate total born and live born piglets. Pigs were cross-fostered within 24 h after farrowing to standardize litter size within dietary treatments. Pigs were weighed after fostering to measure fostered litter weight, and litters were weighed at weaning to determine litter weight gain and survivability.

Data were analyzed as a randomized complete block design with sow as the experimental unit and farrowing group as the blocking criteria. The study was analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Contrasts were used to compare the main effects of grain source, added DDGS, and their interactions. Differences among treatments were considered significant at $P \leq 0.05$ and trends at $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

We observed a tendency for a DDGS × grain source interaction for ADFI from d 0 to 7 ($P = 0.06$) and overall ($P = 0.08$; Table 3). Sows fed the basal corn diet consumed less feed than those fed the corn diet with 20% sorghum DDGS, but sows fed the basal sorghum diet consumed more feed than those fed the sorghum diet with 20% sorghum DDGS (Table 4). The decrease in feed consumption the first 7 d of the study observed for sows fed the sorghum-based diet with 20% sorghum DDGS appeared to be due to the transition from the corn-based diet with 20% corn DDGS in gestation. This result is similar to Wilson et al. (2003[8]), who reported a decrease in feed intake during the first 7 d when DDGS were not fed during gestation. No differences were observed in sow ADFI from d 7 to 14 or d 14 to weaning. For overall (d 0 to 21) ADFI, a tendency ($P < 0.08$) was observed for a DDGS × grain source interaction, with consumption mirroring the trend on d 7. Two sows were removed from the study for the sorghum-based diet and 1 sow from the sorghum-based diet with 20% sorghum-DDGS treatments because of feed refusals. An additional 1 and 2 sows were removed from the study for the sorghum and sorghum-DDGS treatments, respectively, because of illness. When 20% sorghum DDGS were included in the corn- or sorghum-based diets, bulk density of the dietary treatment decreased (Table 2).

No differences were observed among the sows fed the corn- or sorghum-based diets with no DDGS compared with those fed the corn- or sorghum-based diets with 20% sorghum DDGS for sow weaning weight, lactation weight change, or lactation BF

[8] Wilson, J. A., M. H. Whitney, G. C. Shurson, and S. K. Baidoo. 2003. Effects of adding distiller's grains with solubles (DDGS) to gestation and lactation diets on reproductive performance and nutrient balance in sows. J. Anim. Sci. 81(Suppl. 2):47–48. (Abstr.).

change. A decrease ($P < 0.04$) in lactation weight change was found for sows fed diets containing sorghum compared with those fed the corn-based diets.

No differences were observed in the number of pigs weaned or in pig survivability among the dietary treatment groups. Additionally, no differences were observed for litter weaning weight; however, a numerical decrease was observed for sows fed 20% sorghum DDGS. A tendency ($P < 0.06$) for decreased (0.70 lb) individual pig weaning weight was observed for sows fed the diets containing 20% sorghum DDGS. Furthermore, a tendency ($P < 0.09$) for decreased litter weaning weight gain was observed for sows fed diets with 20% sorghum DDGS. The litter weaning weight gain reduction was numerically greater for sows fed the sorghum-based diet with 20% sorghum DDGS than for those fed the corn-based diet with 20% sorghum DDGS.

In conclusion, feeding sows corn- vs. sorghum-based diets (without DDGS) in lactation did not affect litter performance, but the 5% decrease in litter weaning weight of sows fed sorghum with 20% sorghum DDGS needs to be taken into account when selecting ingredients for lactating sows.

Table 1. Ingredient analysis (as-fed basis)[1]

Item, %	Sorghum	Corn	Sorghum dried distillers grains with solubles
DM	88.47	88.05	92.53
CP	8.10	8.61	32.05
Crude fat	2.96	2.72	9.23
Crude fiber	1.36	1.31	7.03
Ash	1.40	1.42	4.19

[1] Values represent the mean of one composite sample of each ingredient.

Table 2. Bulk densities of experimental diets by farrowing group (as-fed basis)[1]

	Grain source			
	Corn		Sorghum	
	DDGS[2] source and level, %			
Item	None 0	Sorghum 20	None 0	Sorghum 20
Bulk density, lb/bushel				
Group 1	57.6	51.7	60.7	52.7
Group 2	53.4	51.4	57.1	52.0
Group 3	52.2	48.2	58.4	50.4
Groups 4 and 5	59.0	51.7	62.2	53.5

[1] Bulk densities represent the mass per unit volume.
[2] Dried distillers grains with solubles.

Table 3. Diet composition (as-fed basis)[1]

	Grain source			
	Corn		Sorghum	
Ingredient, %	None	DDGS[2]	None	DDGS
Corn	66.20	51.85	---	---
Sorghum	---	---	67.05	52.80
Soybean meal (46.5% CP)	30.00	24.50	29.10	23.45
Sorghum DDGS	---	20.00	---	20.00
Monocalcium P (21% P)	1.10	0.60	1.05	0.60
Limestone	1.40	1.66	1.44	1.68
Salt	0.50	0.50	0.50	0.50
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
Sow add pack	0.25	0.25	0.25	0.25
L-lysine HCl	0.03	0.13	0.08	0.18
Phytase[3]	0.14	0.14	0.14	0.14
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lysine	0.97	0.97	0.97	0.97
Isoleucine:lysine	76	79	80	81
Methionine:lysine	29	30	29	30
Met & Cys:lysine	60	61	58	59
Threonine:lysine	66	66	66	66
Tryptophan:lysine	22	21	23	22
Valine:lysine	85	90	88	91
Total lysine, %	1.10	1.13	1.08	1.12
CP, %	19.6	21.5	19.8	21.5
ME, kcal/kg	1,487	1,445	1,463	1,426
Ca, %	0.86	0.86	0.86	0.86
P, %	0.62	0.59	0.62	0.59
Available P, %[4]	0.43	0.43	0.43	0.43

[1] Diets were fed in meal form beginning on d 3 before farrowing.
[2] Dried distillers grains with solubles.
[3] Natuphos classic (BASF Corp.) provided (per kilogram of complete diet): 300 phytase units (FTU) of phytase.
[4] Phytase provided 0.08% available P to the diet.

Table 4. Effects of grain source and sorghum dried distillers grains with solubles (DDGS) on lactating sow and litter performance[1,2]

	Grain source					Probability, *P*<		
	Corn		Sorghum					
	DDGS, %							
	None 0	Sorghum 20	None 0	Sorghum 20	SED	DDGS × grain source	Control vs. DDGS[3]	Corn vs. Sorghum
Sows, n	35	35	32	32				
ADFI, lb								
d 0 to 7	11.43	11.97	12.97	11.70	0.68	0.06	0.44	0.18
d 7 to 14	13.32	13.52	14.19	13.28	0.58	0.17	0.37	0.43
d 14 to weaning	13.47	13.82	14.19	13.28	0.62	0.30	0.81	0.13
d 0 to weaning	12.70	13.08	13.89	12.97	0.53	0.08	0.46	0.15
Sow backfat, mm								
Entry	16.4	15.8	15.7	15.9	0.76	0.80	0.95	0.46
Weaning	14.2	14.3	13.9	13.7	0.87	0.49	0.43	0.06
Change	-1.4	-1.3	-1.7	-2.2	0.62	0.39	0.65	0.15
Sow BW, lb								
Postfarrowing	546.9	537.5	530.9	538.4	14.53	0.40	0.93	0.46
Weaning	515.3	506.9	506.8	517.0	14.21	0.35	0.93	0.93
Change	-31.5	-30.6	-24.2	-21.5	5.84	0.83	0.62	0.04
Piglets								
Litter size, n								
Fostered	12.6	12.7	12.5	12.8	0.24	0.69	0.28	0.75
Weaned	11.8	12.1	11.8	11.8	0.29	0.38	0.48	0.58
Piglet BW, lb								
Fostered litter	43.5	44.5	45.7	43.6	0.24	0.76	0.28	0.62
Pig weaning	13.8	13.3	13.8	13.1	0.44	0.74	0.06	0.72
Litter weaning gain	118.8	116.3	116.1	111.2	5.68	0.76	0.35	0.32
Survivability, %[4]	93.3	95.3	94.8	92.8	1.84	0.11	1.00	0.70

[1] A total of 140 sows (PIC 1050) and their litters were used to determine the effects of sorghum DDGS on lactating sow and litter performance. Two and one sows were removed from the sorghum-based basal diet because of feed refusal and illness, respectively. One and two sows were removed from the sorghum-based diet with 20% sorghum DDGS due to feed refusal and illness, respectively.
[2] Farrowing group was used as a blocking factor.
[3] Basal diets vs. diets with 20% sorghum DDGS.
[4] Survivability was calculated by dividing the weaned litter size by the fostered litter size.

Table 5. Main effects of grain source and sorghum dried distillers grains with solubles (DDGS) on lactating sow and litter performance[1,2]

	Grain source			DDGS, %			Probability, *P*<	
Item	Corn	Sorghum	SED	0	20	SED	Grain source	0 vs. 20% DDGS
Sows								
ADFI, lb								
d 0 to 7	11.7	12.3	0.47	12.2	11.8	0.47	0.18	0.44
d 7 to 14	13.4	13.7	0.40	13.8	13.4	0.40	0.43	0.37
d 14 to weaning	13.6	14.3	0.43	14.0	13.9	0.43	0.13	0.81
d 0 to weaning	12.9	13.4	0.37	13.3	13.0	0.37	0.15	0.46
Sow backfat, mm								
Entry	16.1	15.8	0.43	16.0	15.9	0.43	0.49	0.72
Weaning	14.8	13.8	0.50	14.5	14.1	0.50	0.06	0.43
Change	-1.3	-2.0	0.43	-1.6	-1.8	0.43	0.15	0.65
Sow BW, lb								
Postfarrowing	542.2	534.7	10.1	538.9	538.0	10.1	0.46	0.95
Weaning	511.1	511.9	9.83	511.1	512.0	9.83	0.93	0.93
Change	-31.1	-22.8	4.04	-27.9	-26.0	4.04	0.04	0.65
Piglets								
Litter size, n								
Fostered	12.7	12.6	0.17	12.6	12.7	0.17	0.75	0.28
Weaned	11.9	11.8	0.20	11.8	11.9	0.20	0.58	0.48
Piglet BW, lb								
Foster	44.0	44.6	1.28	44.6	44.1	1.28	0.62	0.68
Litter weaning	161.5	158.3	4.43	162.0	157.8	4.43	0.32	0.34
Pig weaning	13.6	13.5	0.31	13.8	13.2	0.31	0.72	0.06
Litter weaning gain	117.5	113.6	3.93	117.4	113.8	3.93	0.20	0.09
Survivability, %[3]	94.3	93.8	1.27	94.1	94.1	1.27	0.70	1.00

[1] A total of 140 sows (PIC 1050) and their litters were used to determine the effects of sorghum DDGS on lactating sow and litter performance. Two and one sows were removed from the sorghum-based basal diet because of feed refusal and illness, respectively. One and two sows were removed from the sorghum-based diet with 20% sorghum DDGS due to feed refusal and illness, respectively.
[2] Farrowing group was used as the blocking factor.
[3] Survivability was calculated by dividing the weaned litter size by the fostered litter size.

An Evaluation of Supplemental Vitamin D_3 on Growth Performance of Pigs Pre- and Postweaning, Nursery Feed Preference, and Serum $25(OH)D_3$[1]

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Summary

Three experiments were conducted to evaluate the effects of supplementing different concentrations and sources of vitamin D_3 on pig performance, feed preference, and serum $25(OH)D_3$.

In Exp. 1, a total of 398 barrows from 80 litters (PIC 1050, initially 7 d of age) were used in a 38-d study in a 2 × 2 factorial to determine the effects of vitamin D_3 supplementation from either a single oral dose or from high levels of vitamin D_3 in early nursery diets on pig performance and serum $25(OH)D_3$. On d 7 after birth, matched sets of pigs within litters were allotted to 1 of 2 oral dosages (none or 40,000 IU vitamin D_3) in a randomized complete block design. Pigs were weighed at d 7 and at weaning (d 21). Following weaning, a subset of 300 barrows were used from d 21 to 45 to determine the effects of the previously administered oral vitamin D_3 and 2 levels of dietary vitamin D_3 (625 or 6,250 IU/lb; 0.80% Ca and 0.63% available P) from weaning to d 31 on pig growth and serum $25(OH)D_3$. A common diet containing 625 IU/lb of vitamin D_3 (0.70% Ca and 0.47% available P) was fed from 31 to 45 d of age. No dose × diet interactions ($P > 0.09$) were observed. Serum $25(OH)D_3$ increased ($P < 0.01$) on d 21 and tended to increase on d 31 after dosing pigs with oral vitamin D_3 prior to weaning. On d 31, serum concentrations increased with increasing dietary vitamin D_3 levels ($P < 0.01$). Weaning weight was not influenced ($P > 0.17$) by the oral dose of vitamin D_3. Supplementing vitamin D_3 by either dose or diet did not influence ($P > 0.23$) nursery performance.

In Exp. 2, a total of 864 pigs (PIC TR4 × FAST ADN, initially 21 d of age) were used in a 30-d study to determine the effects of water supplementation of vitamin D_3 on nursery growth performance and serum $25(OH)D_3$. Upon arrival to the nursery (d 0), pigs were allocated to pens and pens were randomly allotted to 1 of 2 water vitamin D_3

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[3] PA, Abilene Animal Hospital, Abilene, KS.
[4] Innovative Swine Solutions, Carthage, IL.
[5] New Fashion Pork Inc., Jackson, MN.
[6] Hubbard Feeds, Mankato, MN.

supplementation treatments (none or 4,000,000 IU/gal). There were 24 pigs/pen and 18 pens/treatment. Pigs were provided the water supplementation treatments from d 0 to 10. From d 10 to 30, pigs were administered water with no supplemental vitamin D_3. Common diets were fed throughout the study and were formulated to contain 1,000 IU/lb added vitamin D_3. Twelve pigs per treatment were randomly selected to be bled on d 0, 10, 20, and 30 to determine serum 25(OH)D_3 concentrations. Water supplementation of vitamin D_3 increased ($P < 0.01$) serum 25(OH)D_3 concentrations on d 10, 20, and 30 of the study but did not affect ($P > 0.15$) nursery growth performance.

In Exp. 3, 72 pigs (PIC 327 × 1050, initially 28 d of age) were used in 2 14-d feed preference comparisons to determine whether pigs discriminate in their choice of feeds containing different concentrations of vitamin D_3. On d 0, pigs were weighed and allotted to pens based on BW with 6 pigs/pen and 6 pens per feed comparison. The first preference comparison was between diets containing either 625 (control) or 6,250 IU/lb vitamin D_3, and the second comparison was between diets containing 625 (control) or 20,000 IU/lb vitamin D_3. Total pen feed intake was measured, and intake of each diet was expressed as a percentage of total intake. The percentage of feed intake did not differ ($P > 0.14$) between the control diet and the diet containing 6,250 IU/lb, but pigs chose to consume a greater percentage ($P < 0.01$) of the control diet (77%) than the diet containing 20,000 IU/lb of vitamin D_3.

These experiments demonstrated that providing high levels of vitamin D_3 in an oral dosage, in the water, or in feed increased serum 25(OH)D_3; however, preweaning and nursery pig growth performance was not influenced by elevating vitamin D_3 above normal dietary levels.

Key words: nursery pig, vitamin D

Introduction

Vitamin D is a fat-soluble steroid known for its role in the absorption and homeostasis of Ca and P in the body. The two main forms of vitamin D are vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol). Previous research has shown that pigs discriminate in the metabolism of these two forms and more readily convert vitamin D_3 to its circulating metabolite 25(OH)D_3. This metabolite of vitamin D is the main circulating form in the blood and acts as a clinically useful marker for vitamin D status. In recent years, more focus has been placed on vitamin D because of documented cases where it has been absent from premixes fed to pigs. In these cases, large percentages of pigs have reportedly developed metabolic bone disease, which is categorized as disturbances related to bone formation and remodeling and can lead to bone breakages and clinical symptoms of rickets. Previous work conducted at Kansas State University (Flohr et al., 2011[7]) has shown that supplementation of vitamin D_3 (40,000 or 80,000 IU) given in a single oral dose after birth can increase serum 25(OH)D_3 concentrations of pigs up to 10 d after weaning, but no benefit in growth performance or bone mineralization was observed. Further research is needed to determine whether pig performance can be influenced by oral supplementation of high levels of vitamin D_3.

[7] Flohr et al., Swine Day 2011. Report of Progress 1056. pp. 34–45.

These experiments were designed to: (1) evaluate the effects of supplementing vitamin D_3 in a single oral dose on growth performance of suckling pigs in a commercial facility, (2) evaluate the effect of supplementing additional vitamin D_3 in early nursery diets or by water supplementation on pig growth performance and serum 25(OH)D_3 concentrations in the nursery, and (3) determine any potential preferences of young pigs to consume diets with different concentrations of supplemental vitamin D_3.

Procedures

The protocols in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The preweaning portion of Exp. 1 was conducted at Innovative Swine Solutions in Carthage, IL, and the nursery portion was performed at the K-State Segregated Early Weaning Facility in Manhattan, KS. Experiment 2 was conducted at New Fashion Pork in Buffalo Center, IN. Experiment 3 was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

For Exp. 1, a total of 398 barrows from 80 litters (PIC 1050, initially 7 d of age) were used in a 38-d study in a 2 × 2 factorial to determine the effects of supplementing vitamin D_3 from either a single oral dose or from high concentrations in early nursery diets on pig growth performance and serum 25(OH)D_3. On d 7 after birth, matched pairs of pigs within litters were allotted to 1 of 2 oral dosage treatments (none or 40,000 IU vitamin D_3) in a randomized complete block design. Pigs were weighed on d 7 and at weaning (d 21). Following weaning, a subset of 300 barrows were used from d 21 to 45 to determine the effects of the previously administered vitamin D_3 dose and 2 levels of dietary vitamin D_3 (625 or 6,250 IU/lb vitamin D_3, 0.80% Ca, and 0.63% available P; Table 1) from weaning through d 31 on pig performance and serum 25(OH)D_3. Common diets (625 IU/lb vitamin D_3, 0.70% Ca, and 0.47% available P) were fed from d 31 to 45. Barrows were allotted to pens based on their previously administered oral vitamin D_3 dose, then pens were randomly assigned to dietary treatments. All pens contained a 4-hole dry self-feeder and a cup waterer to allow for ad libitum access to feed and water.

Pigs and feeders were weighed on d 21, 26, 31, 38, and 45 to determine ADG, ADFI, and F/G. Serum was collected from 12 pigs per treatment via jugular venipuncture at weaning (d 21), d 31, and d 45. To select pigs bled for serum, the average weight pig from each of 12 pens/treatment were used. All blood samples were collected in serum separator tubes and were refrigerated for at least 6 h after collection. Blood was centrifuged at 1,600 × g for 25 min. Serum was extracted and stored in 2-mL vials and frozen in a freezer at -4°F. All 25(OH)D_3 testing was performed by Heartland Assays Inc. (Ames, IA). Additionally, barrows were vaccinated for porcine circovirus type 2 (PCV2) and Mycoplasma hyopnuemoniae (M. hyo). A 1-dose product, Ingelvac CircoFLEX (CircoFLEX; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO) was given for PCV2. For the *Mycoplasma hyopneumoniae* (*M. hyo*) vaccine, Respisure (Pfizer Animal Health, New York, NY), a 2-dose product was used. Serum samples collected at weaning and on d 64 (5 wk postvaccination) were analyzed for PCV antibody titers to distinguish potential effects of supplemental vitamin D_3 on acquired immunity. Serum was analyzed at the K-State Veterinary Diagnostic Laboratory using indirect fluorescent assays (IFA). Titration endpoints were calculated as the reciprocal of the last serum dilution that gave a positive fluorescence result. Prior to analysis, all IFA titers were

log_2-transformed to approximate a normal distribution of titers. Log_2-transformed antibody titers were used to quantify the change in antibody titers from weaning (d 21) through d 64 based on supplemental vitamin D_3 treatments.

In Exp. 2, 864 pigs (PIC TR4 × FAST ADN; initially 21 d of age) were used in a 30-d nursery study to determine the effects of water supplementation of vitamin D_3 on nursery pig growth performance and serum 25(OH)D_3 concentrations. Pigs were placed in pens upon arrival in the nursery facility with 24 pigs/pen. Pens were randomly allotted to 1 of 2 water vitamin D_3 supplementation treatments (none or 4,000,000 IU/gal). The 4,000,000 IU dose was provided by mixing Hi-D 2X (Alpharma, Inc.) at 2 oz/gal. Each treatment comprised 18 pens. Pens contained a 5-hole dry self-feeder and nipple waterer to allow for ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 10, 20, and 30 to determine ADG, ADFI, and F/G. Twelve pigs/treatment were bled via jugular venipuncture on d 0, 10, 20, and 30 to determine 25(OH)D_3 concentrations. All blood samples were collected in serum separator tubes and refrigerated for at least 6 h after collection. Blood was centrifuged at 1,600 × g for 25 min. Serum was extracted and stored in 2-mL vials and frozen in a freezer at -4°F. All 25(OH)D_3 testing was performed by Heartland Assays Inc. (Ames, IA).

In Exp. 3, 72 pigs (PIC 327 × 1050, initially 28 d of age) were used in 2 14-d feed preference comparisons to evaluate if pigs differentiate between feeds containing different levels of vitamin D_3. All pigs received a common Phase 1 diet for 7 d prior to the start of the study. On d 0 (7 d postweaning), pigs were weighed and allotted to pens based on BW. There were 6 pigs/pen and 6 pens per treatment, and pens were randomly assigned to 1 of the 2 feed comparisons between Phase 2 nursery diets (Table 1). The first preference comparison was between diets containing 625 (control) or 6,250 IU/lb vitamin D_3, and the second comparison was between diets containing 625 (control) or 20,000 IU/lb vitamin D_3. Pens contained two 4-hole dry self-feeders and a nipple waterer to allow for ad libitum access to feed and water. Diets were placed in the separate feeders and feeders were positioned adjacent to each other. Every morning, feeders were weighed and switched in pen location to discourage any location bias by the pig. Total pen feed intake was calculated, and intake of each diet for both comparisons was expressed as a percentage of total intake.

Vitamin premixes and feed samples used in Exp. 1 and 3 were collected and sent to DSM Nutritional Products Laboratory, Inc. (Parsippany, NJ) for vitamin D_3 analysis (Table 2). Accepted analytical errors associated with complete feed vitamin D_3 assays is ± 25% of target level. All diets were within ±25% of their formulated level.

Statistical analysis conducted for each experiment was performed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). In Exp. 1, for the preweaning period, the growth data were analyzed as a randomized complete block design. Individual pig was the experimental unit, initial weight on the day of dosing was used as a covariate, and sow was used as a random effect. Only pigs that completed the full lactation period (d 7 to 21) were used in this analysis. Nursery growth performance data were analyzed as a completely randomized design using pen as the experimental unit and barn as a random effect. Serum 25(OH)D_3 and PCV antibody titer results were analyzed using the repeated measures function to determine the effect of dosage or diet on response criteria over time and the treatment × time interactions. For Exp. 2, pen was the experimental unit, and initial BW on d 0 was used as a covariate. Serum 25(OH)D_3 was analyzed using the repeated measures function to determine the effect of water vitamin D_3 supplementation on serum over time and the treatment × time interactions. For Exp. 3, pen was again the experimental unit, and differences associated with the main effect of diet on the percentage of total feed intake were determined in both comparisons. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

In Exp. 1, no differences were observed ($P > 0.17$) for weaning weight (Table 3), but weaning weights were 0.2 lb/pig numerically heavier for pigs supplemented with the oral dosage of 40,000 IU of vitamin D_3. During the nursery phase (d 21 to 45), neither previously administered oral vitamin D_3 dose nor dietary level of vitamin D_3 in the diet affected ($P > 0.23$) ADG, ADFI, or F/G (Table 4). No dose × diet interactions were observed for any criteria in Exp. 1 except for a tendency ($P = 0.06$) for F/G from d 21 to 31. Here, F/G worsened with increasing dietary vitamin D_3 for pigs initially dosed on d 7 with 40,000 IU, but for pigs not orally dosed with vitamin D_3, F/G improved with increasing dietary vitamin D_3.

At weaning (d 21), serum 25(OH)D_3 concentrations (Table 5) increased ($P < 0.01$) in pigs that received an oral dose of 40,000 IU vitamin D_3. On d 31, a tendency ($P = 0.08$) for an increase in serum 25(OH)D_3 was observed for pigs dosed with vitamin D_3 prior to weaning. Also on d 31, increased serum 25(OH)D_3 concentrations were observed ($P < 0.01$) in pigs fed increased levels of vitamin D_3 (Figure 1).

PCV antibody titer results showed no dose × diet interaction ($P = 0.74$; Table 6) and no main effects of either dose or diet ($P > 0.59$) associated with the change in $\log_2$ reciprocal dilutions from d 21 to d 64.

In Exp. 2, supplementation of vitamin D_3 through the water did not affect ($P > 0.15$) overall ADG, ADFI, or F/G (Table 7), but F/G improved ($P = 0.05$) during the first phase (d 0 through 10) in pigs supplemented with 4,000,000 IU/ gallon of vitamin D_3. On the other hand, from d 10 to 30, ADG decreased significantly ($P = 0.03$) and F/G worsened ($P = 0.05$) in pigs supplemented 4,000,000 IU vitamin D_3 during the first phase.

For serum 25(OH)D_3 concentrations (Table 8), supplementing 4,000,000 IU vitamin D_3/gallon from d 0 to 10 increased ($P < 0.01$) serum 25(OH)D_3 concentrations in pigs on d 10, 20, and 30 (Figure 2).

In Exp. 3, there was no difference in preference between diets containing 625 or 6,250 IU of vitamin D_3 (Table 9), but when pigs were offered a choice between diets containing 625 and 20,000 IU of vitamin D_3, they consumed a greater portion ($P < 0.01$) of the diet containing 625 IU of vitamin D_3.

Results from Exp. 1 and Exp. 2 agree with our previous research (Flohr et al., 2011). Supplementation of vitamin D_3 appeared to significantly increase serum 25(OH)D_3 concentrations in the weaned pig but did not lead to increases in growth performance.

These studies clearly demonstrate that increasing supplementation of vitamin D_3 through an oral dose, diet, or water can increase serum 25(OH)D_3.

Porcine circovirus type 2 antibody titer results from Exp. 1 suggest that vitamin D_3 supplementation has no effect on acquired immunity of the nursery pig, but to truly quantify vitamin D's role in immune function, disease challenge or studies with additional vaccines should be conducted.

In Exp. 3, the studies suggest that young pigs have a truly wide range of acceptance for different dietary vitamin D_3 concentrations; however, when diets contain extremely high concentrations (20,000 IU/lb) of vitamin D_3, pigs will reduce intake of the diet, which could potentially have negative effects on growth performance. If additional supplementation of vitamin D_3 is utilized in an operation, dietary levels should be monitored to reduce the risk of negative effects in growth performance or potential for vitamin D toxicity.

Multiple studies conducted at K-State associated with the supplementation of additional vitamin D_3 to the nursery pig have consistently shown that serum 25(OH)D_3 concentrations can be increased without influence on growth performance of pigs pre- or postweaning. Future research needs to better quantify the relationship of circulating 25(OH)D_3 to proper bone mineralization and ideal Ca and P absorption to determine optimal circulating concentrations of 25(OH)D_3. More information is needed to determine whether another metabolite or other related protein may better quantify vitamin D status.

Table 1. Diet composition (as-fed basis)[1]

	Exp. 1[2]		Exp. 3[3]		
	Phase 1 diets		Phase 2 diets		
Ingredient,% vitamin D_3, IU/lb:	625	6,250	625	6,250	20,000
Corn	39.57	39.47	56.58	56.58	56.58
Soybean meal (46.5% CP)	17.34	17.34	26.30	26.30	26.30
Select menhaden fish meal	---	---	4.50	4.50	4.50
Dried distillers grains with solubles	5.00	5.00	---	---	---
Spray-dried porcine plasma	5.00	5.00	---	---	---
Spray-dried blood cells	1.25	1.25	---	---	---
Spray-dried whey	25.00	25.00	10.00	10.00	10.00
Soybean oil	3.00	3.00	---	---	---
Vitamins and minerals	2.64	2.64	1.66	1.66	1.66
Zinc oxide	0.39	0.39	0.25	0.25	0.25
Vitamin D premix[4]	---	0.10	0.05	0.05	0.05
Amino acids	0.48	0.48	0.49	0.49	0.49
Phytase[5]	0.13	0.13	0.17	0.17	0.17
Acidifier[6]	0.20	0.20	---	---	---
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
ME, kcal/lb	1,548	1,548	1,504	1,504	1,504
Total lysine, %	1.50	1.50	1.44	1.44	1.44
CP, %	21.2	21.2	21.5	21.5	21.5
Standardized ileal digestible amino acids, %					
Lysine	1.35	1.35	1.31	1.31	1.31
Isoleucine:lysine	61	61	61	61	61
Methionine:lysine	29	29	35	35	35
Met & Cys:lysine	58	58	59	59	59
Threonine:lysine	64	64	63	63	63
Tryptophan:lysine	18	18	17	17	17
Valine:lysine	72	72	68	68	68
Ca, %	0.80	0.80	0.71	0.71	0.71
P, %	0.71	0.71	0.63	0.63	0.63
Available P, %	0.63	0.63	0.47	0.47	0.47
Ca:P	1.13	1.13	1.12	1.12	1.12

continued

Table 1. Diet composition (as-fed basis)[1]

	Exp. 1[2]		Exp. 3[3]		
	Phase 1 diets		Phase 2 diets		
Ingredient,% vitamin D_3, IU/lb:	625	6,250	625	6,250	20,000
Vitamins (added levels)					
Vit A, IU/ton	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
Vit D, IU/ton	1,250,000	12,500,000	1,250,000	12,500,000	40,000,000
Vit E, IU/ton	40,000	40,000	40,000	40,000	40,000
Vit K (menadione), mg/ton	4,000	4,000	4,000	4,000	4,000
Vit B_{12}, mg/ton	35	35	35	35	35
Niacin, mg/ton	45,000	45,000	45,000	45,000	45,000
Pantothenic acid, mg/ton	25,000	25,000	25,000	25,000	25,000
Riboflavin, mg/ton	7,500	7,500	7,500	7,500	7,500

[1] Diets from Exp. 2 were not included because experimental vitamin D_3 levels were achieved by water supplementation.
[2] A total of 300 barrows (PIC 1050, initially 21 d of age) were used for 24 d as part of a 38-d study evaluating the effects of supplemental vitamin D_3 by an oral dose or in early nursery diets on nursery growth performance and serum 25(OH)D_3 concentrations. Phase 1 experimental diets were fed from weaning (d 21) to d 31, then a common Phase 2 diet was fed from d 31 to 45.
[3] A total of 72 pigs (PIC 327 × 1050 initially 28 d of age) were used in two 14-d feed preference comparisons to evaluate if pigs differentiate between feeds containing different levels of vitamin D_3.
[4] Vitamin D premix was made by mixing rice hulls with Rovimix D_3 (DSM Nutritional Products, Parsippany, NJ) to achieve desired dietary vitamin D_3 concentration.
[5] Natuphos 600, BASF, Florham Park, NJ. Provided 354 and 463 phytase units (FTU) per pound of diet for Phase 1 and Phase 2 diets, respectively.
[6] KemGest, Kemin Industries Inc., Des Moines, IA.

Table 2. Analyzed dietary vitamin D_3 content of experimental rations (Exp. 1 and 3)[1,2]

	Exp. 1		Exp. 3		
Formulated level, IU/lb	625	6,250	625	6,250	20,000
Analyzed level, IU/lb	576	4,703	776	7,055	22,500
Analytical error[3]	± 25%	± 20%	± 25%	± 20%	± 15%

[1] Diets from Exp. 2 were not included because supplemental vitamin D_3 levels were achieved by water supplementation.
[2] All dietary vitamin D_3 analyses were conducted by DSM Nutritional Products Laboratory Inc. (Parsippany, NJ).
[3] Laboratory assay variability associated with vitamin D_3 content.

Table 3. Effects of oral vitamin D_3 dose on preweaning performance (Exp. 1)[1,2]

Item Oral vitamin D_3:	None	40,000 IU	SEM	Probability, *P*<
No. of pigs weaned	200	198	---	---
Weaning weight, lb	11.40	11.58	0.134	0.17
Weight gain, lb	7.07	7.25	0.134	0.17

[1] A total of 398 barrows from 80 litters (PIC 1050, initially 7 d of age) were used in a 14-d preweaning study to determine the effect of supplementing a single oral dose of vitamin D_3 on preweaning growth performance.
[2] Initial BW (d 7) was used as a covariate and sow was included in the statistical model as a random effect.

Table 4. Effects of supplemental vitamin D_3 by an oral dose or in early nursery diets on nursery pig growth performance (Exp. 1)[1]

Oral dosage[2]:	None		40,000 IU D_3			Probability, *P*<		
Dietary D_3, IU/lb[3]:	625	6,250	625	6,250	SEM	Dose × diet interaction	Dosage	Diet
d 21 to 31								
ADG, lb	0.35	0.36	0.37	0.33	0.021	0.15	0.80	0.46
ADFI, lb	0.34	0.34	0.35	0.34	0.028	0.84	0.51	0.56
F/G	0.99	0.95	0.97	1.04	0.035	0.06	0.25	0.66
d 31 to 45								
ADG, lb	0.93	0.90	0.89	0.93	0.023	0.17	0.85	0.95
ADFI, lb	1.22	1.19	1.19	1.22	0.024	0.14	0.97	0.99
F/G	1.32	1.33	1.33	1.32	0.021	0.64	0.89	0.94
d 21 to 45								
ADG, lb	0.68	0.67	0.67	0.68	0.017	0.59	0.83	0.92
ADFI, lb	0.85	0.83	0.84	0.86	0.020	0.28	0.83	0.99
F/G	1.25	1.24	1.25	1.26	0.020	0.62	0.67	0.85

[1] A total of 300 barrows were used from d 21 to 45 of age to determine the effects of supplemental vitamin D_3 on nursery growth performance from either a single oral dose or in early nursery diets. There were 5 barrows per pen and 15 pens per treatment.
[2] Oral dosage treatments were administered at d 7 of age.
[3] Dietary vitamin D_3 levels were fed in Phase 1 diets (d 21 to 31), then pigs were fed common diets containing 625 IU/lb vitamin D_3 from d 31 to 45.

Table 5. Effects of supplemental vitamin D_3 from either an oral dose or in early nursery diets on serum 25(OH) D_3 concentrations (Exp. 1)[1,2]

Dosage:	No vitamin D_3		40,000 IU D_3			Probability, *P*<		
Dietary D_3, IU/lb:	625	6,250	625	6,250	SEM	Dose × diet interaction	Dosage	Diet
25(OH)D_3, ng/mL								
d 21	7.8	7.9	26.8	21.6	2.59	0.30	0.01	0.32
d 31	21.3	33.5	28.6	35.6	2.59	0.33	0.08	0.01
d 45	10.1	14.3	15.6	13.7	2.59	0.25	0.35	0.66

[1] Twelve pigs/treatment were bled on d 21 (weaning), 31, and 45 to determine serum 25(OH)D_3 concentrations.
[2] Dose × diet × day interaction ($P = 0.99$), day main effect ($P < 0.01$).

Table 6. Effects of supplemental vitamin D_3 by an oral dose or in early nursery diets on PCV2 antibody titers[1,2]

Oral dosage:	No Vitamin D_3		40,000 IU D_3			*Probability, P*<		
Dietary D_3, IU/lb:	625	6,250	625	6,250	SEM	Dose × diet interaction	Dosage	Diet
PCV2 antibody titer, log_2								
d 21 (weaning)	6.6	7.6	6.6	6.6	0.41	0.16	0.14	0.21
d 64 (5 w postvaccination)	8.4	9.4	7.5	8.2	1.02	0.84	0.23	0.35
Change (d 64 to d 21)	1.8	1.8	0.9	1.6	1.13	0.74	0.59	0.70

[1] Serum collected on d 21 (weaning) and 5 wk postvaccination (d 64) was sent to the K-State Veterinary Diagnostic Laboratory for indirect fluorescent assays. There were 12 samples/treatment.
[2] Endpoint antibody titers determined by indirect fluorescent antibody (IFA) assay were log_2-transformed.

Table 7. Effects of water supplemented vitamin D_3 on nursery growth performance (Exp. 2)[1,2]

	Water supplemented D_3, IU/gal			
	None	4,000,000[3]	SEM	Probability, $P<$
d 0 to 10[4]				
ADG, lb	0.56	0.57	0.014	0.63
ADFI, lb	0.57	0.56	0.012	0.75
F/G	1.01	0.98	0.013	0.05
d 10 to 30				
ADG, lb	1.27	1.24	0.011	0.03
ADFI, lb	1.66	1.63	0.017	0.30
F/G	1.30	1.32	0.007	0.05
d 0 to 30				
ADG, lb	1.04	1.01	0.010	0.15
ADFI, lb	1.29	1.27	0.014	0.31
F/G	1.25	1.25	0.004	0.28

[1] A total of 864 pigs (PIC TR4 × FAST AND; initially 21 d of age) were used in a 30-d nursery study to determine the effects of water supplementation of vitamin D_3 on growth performance.
[2] Common diets formulated to contain 1,000 IU/lb of vitamin D_3 were provided throughout the trial.
[3] Hi-D 2X (Alpharma, Inc.) was included in water source at a rate of 2 oz/gal to achieve the desired experimental treatment level.
[4] Experimental water treatments were administered from d 0 to 10; from d 10 to 30, pigs were provided a control water source with no supplemental vitamin D_3

Table 8. Effects of water supplemented vitamin D_3 on serum 25(OH)D_3 (Exp. 2)[1,2]

	Water supplemented D_3, IU/gal:			
	None	4,000,000[2]	SEM	Probability, $P<$
Serum 25(OH)D_3, ng/mL				
d 0	11.6	16.0	2.79	0.27
d 10	27.4	90.2	2.79	< 0.01
d 20	17.8	47.7	2.79	< 0.01
d 30	21.0	32.6	2.79	< 0.01

[1] A total of 12 pigs/treatment were bled via jugular venipuncture to determine serum 25(OH)D_3 concentrations.
[2] Day × treatment interaction ($P < 0.01$), day main effect ($P < 0.01$).

Table 9. Evaluation of nursery pig feed preference for diets formulated to varying levels of vitamin D_3 (Exp. 3)[1]

Feed comparison:[2]	1				2			
Dietary vitamin D_3, IU/lb:	625	6,250	SEM	*Probability, P<*	625	20,000	SEM	Probability, *P*<
Feed intake, %								
d 0 to 7	54.5	45.5	4.2	0.14	77.7	22.3	4.20	< 0.01
d 7 to 14	46.4	53.6	6.7	0.46	61.4	38.6	6.74	0.03
d 0 to 14	49.3	50.7	5.2	0.85	66.9	33.1	5.20	< 0.01

[1] A total of 72 pigs (PIC 327 × 1050; initially 28 d of age) were used in a 14-d feed comparison to evaluate nursery pig preference to diets containing varying levels of vitamin D_3.
[2] There were 6 pigs/pen and 6 pens/feed comparison.

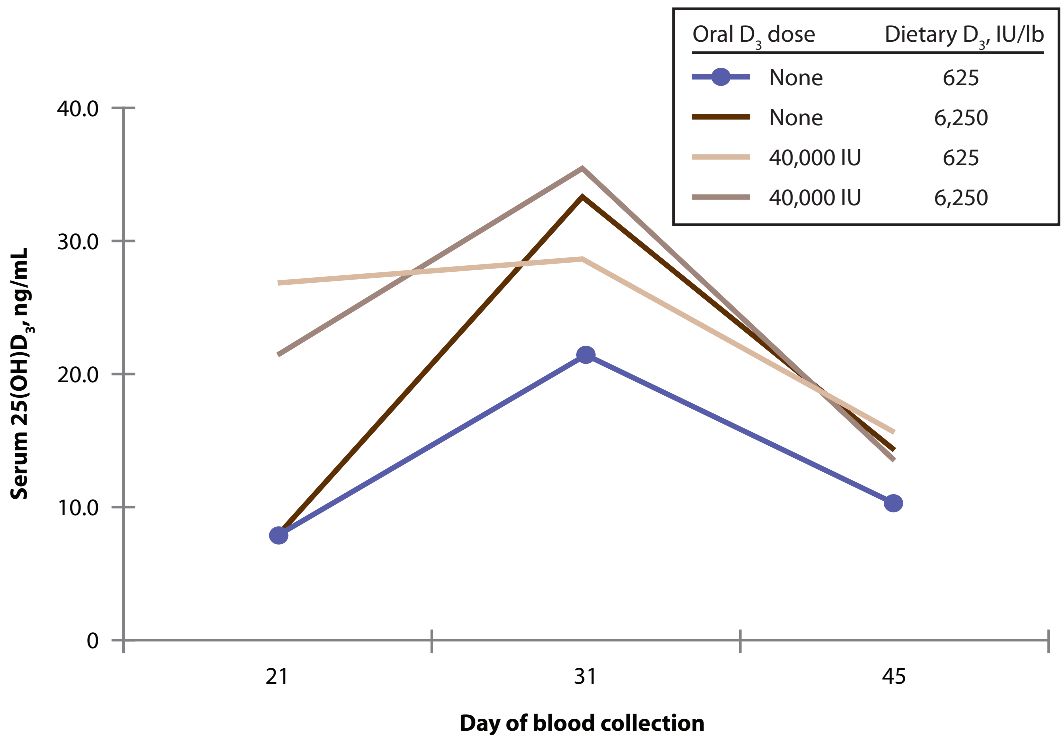

Figure 1. Effects of supplemental vitamin D_3 by either an oral dose or in early nursery diets on serum 25(OH) D_3 concentrations as determined by jugular venipuncture of 12 pigs/treatment on d 21 (weaning), 31, and 45 (Exp. 1).

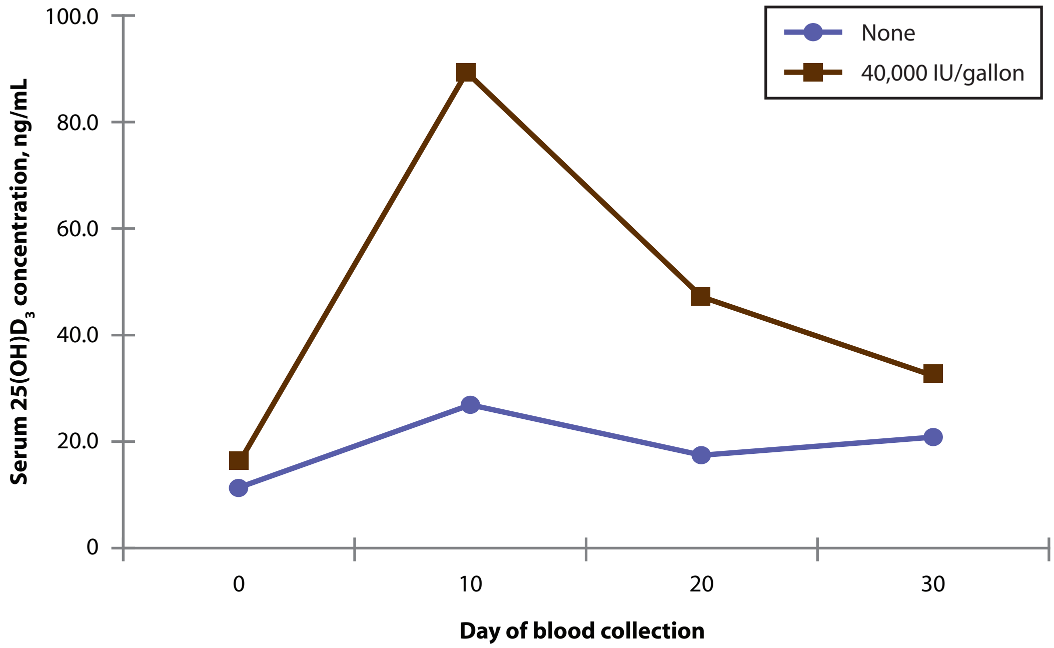

Figure 2. Effects of water supplementation of vitamin D_3 on serum 25(OH) D_3 concentrations as determined by jugular venipuncture of 12 pigs/treatment on d 0 (weaning), 10, 20, and 30 (Exp. 2).

An Evaluation of Dietary Natural Zeolite or Humic Acid Substances and Sulfate Water on Nursery Pig Performance[1]

J. R. Flohr, M. D. Tokach, J. L. Nelssen, S. S. Dritz[2], J. M. DeRouchey, and R. D. Goodband

Summary
A total of 350 nursery pigs (PIC 1050 barrows, initially 21 d of age) were used in a 21-d study to determine the effects of high-sulfate water, dietary natural zeolite, and dietary humic substances on growth performance and fecal consistency of nursery pigs. Ten treatments were arranged as a 2 × 5 factorial with 2 water treatments (control or water with 2,000 ppm sodium sulfate) and 5 dietary treatments (control, 1 or 2% zeolite, 1% humic acid substance [HA], or 1% humic and fulvic acid blended substance [HFB]). Water treatments remained the same from d 0 to 21 and all diets were fed in 2 phases, with diets containing feed additives at the same inclusion rate in both phases. Phase 1 diets were fed in a pellet form from d 0 to 8 after weaning; Phase 2 diets were fed in meal form from d 8 to 21. Fecal samples were collected on d 5, 8, 15, and 21. These samples were visually assessed and scored on a scale of 1 to 5 to determine consistency of the fecal samples, then analyzed for DM.

Overall (d 0 to 21), a water source × diet interaction ($P < 0.03$) occurred for ADG and F/G. The interaction occurred because pigs fed 1% HA had poorer ($P < 0.01$) ADG and F/G than other treatments when drinking 2,000 ppm sodium sulfate water but improved ADG and F/G when drinking control water. Pigs drinking 2,000 ppm sodium sulfate water had poorer ($P = 0.01$) ADG and F/G and a tendency ($P = 0.08$) for lower ADFI than pigs drinking the control water. No significant main effects of diet were observed for growth performance criteria. Pigs drinking 2,000 ppm sodium sulfate water had more fluid fecal samples ($P < 0.01$) than pigs drinking control water. For fecal DM, pigs drinking 2,000 ppm sodium sulfate water had lower ($P < 0.01$) fecal DM on d 5 and 8 and lower overall mean fecal DM than pigs drinking control water.

Pigs drinking water with 2,000 ppm sodium sulfate had decreased ADG, poorer F/G, and tended to have lower ADFI for the overall trial than those drinking control water; they also had more watery feces on d 5 and 8 as measured by lower fecal DM compared with pigs drinking control water. The zeolite or humic acid products tested did not improve pig performance or alter fecal DM.

Key words: nursery pig, sulfate, water, zeolite, humic substances

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[1] The authors would like to thank St. Cloud Mining Co., Truth or Consequences, NM, for providing the zeolite used in this study and Humatech Inc., Houston, TX, for providing the humic acid products used in this study.
[2] Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

Introduction

Signs of diarrhea and more fluid feces are many times associated with an infectious disease challenge and the stress that accompanies weaning. Other factors that can contribute to these signs are water quality and high-protein diets. High sulfate concentrations within groundwater supplies have been associated with more fluid fecal production and reductions in performance (Anderson et al., 1994[3]) when concentrations exceed 7,000 ppm. At concentrations less than 3,000 ppm, research has shown that sulfates act as a natural laxative and can cause less firm feces but do not affect growth performance (Patience et al., 2004[4]). A previous study conducted at K-State (Flohr et al., 2011[5]) showed that using a 3,000 ppm sodium sulfate challenge model decreased growth performance and increased the fecal moisture content and clinical diarrhea score of weaned pigs.

A similar model is utilized at the University of Guelph to induce colitis in swine as a model for human Inflammatory Bowel Disease research. In this model, pigs are orally dosed with dextran sodium sulfate (DSS). Work conducted with the model has consistently shown that oral DSS administration results in clinical signs of pro-inflammatory cytokine activity that can inhibit ideal water balance and absorption. Ultimately, high sulfate concentrations in water supplies can increase production costs, either from antibiotic treatment of pigs displaying signs of enteric disease (diarrhea) or from reductions in performance.

Zeolites are microporous aluminosilicate minerals composed of alkali and alkaline earth cations along with small amounts of other elements. The zeolite molecules are arranged in 3-dimensional structures that create interconnected channels capable of trapping molecules of proper dimensions similar to that of a sieve. Zeolite molecules can also bind and release specific molecules by adsorption or ion exchange. In industrial operations, zeolites have been used as detergents because of their ability to bind with water and other molecules. In agriculture, zeolites frequently have been used to reduce odor because of their ability to bind with ammonia. Flohr et al. (2011) showed that adding up to 1% zeolite to the diet of nursery pigs following weaning resulted in a linear increase in feed intake, but no changes in scour score were associated with increasing the amount of zeolite added to the diet.

Humic substances, another natural feed additive, have been used in nursery diets to decrease the incidence and severity of diarrhea. Humic substances can include most of the organic matter found in many soils, but its largest constituents include humic acid, fulvic acid, and humin. These substances can include several other minerals such as iron, manganese, copper, and zinc. Ji et al. (2006[6]) reported improved ADG and F/G for 2 specialized humic substances with varying concentrations of humic and fulvic acid.

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[3] Anderson, J. S., D.M. Anderson, and J.M. Murphy. 1994. The effect of water quality on nutrient availability for grower/finisher pigs. Can. J. Anim. Sci. 74:141–148.

[4] Patience J. F., A. D. Beaulieu, and D. A. Gillis. 2004. The impact of ground water high in sulfates on the growth performance, nutrient utilization, and tissue mineral levels of pigs housed under commercial conditions. J. Swine Health Prod. 12(5):228–236.

[5] Flohr et al., Swine Day 2011, Report of Progress 1056, pp. 46–56.

[6] F. Ji, J. J. Mcglone, and S. W. Kim. 2006. Effects of dietary humic substances on pig growth performance, carcass characteristics, and ammonia emission. J. Anim. Sci. 84:2482–2490.

The objectives of this study were to determine if adding natural zeolite (clinoptilolite) and humic and fulvic acid substances to the diet might mitigate the incidence and severity of diarrhea caused by adding 2,000 ppm sodium sulfate to the water supply of weaned pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS.

A total of 350 nursery pigs (PIC 1050 barrows, initially 12.5 lb and 21 d of age) were allotted to 1 of 10 treatments arranged in a 2 × 5 factorial with main effects of water source (control or water containing 2,000 ppm sodium sulfate) and dietary regimen (control [no added zeolite or humic substances], 1% zeolite [clinoptilolite], 2% zeolite [clinoptilolite], 1% HA, and 1% HFB. There were 5 pigs per pen and 7 pens per treatment. Pigs were provided unlimited access to feed and water through a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft).

Chemical composition of the natural zeolite (clinoptilolite) and the humic substances used in the experiment are shown in Table 1. All diets were fed in 2 phases (Table 2), and the dietary experimental feed additive additions were the same in both phases. Phase 1 diets were fed in a pellet form from d 0 to 8 after weaning. Phase 2 diets were fed in a meal form from d 8 to 21. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 5, 8, 15, and 21.

For the sodium sulfate water treatment, sodium sulfate was mixed in a stock solution and administered in the water supply (Manhattan, KS, municipal water source) of the corresponding pens by a medicator (Dosatron; Dosatron International Inc., Clearwater, FL) at the rate of 1:10 to provide 2,000 ppm of sodium sulfate. Two water samples were collected from both the control water and 2,000 ppm sodium sulfate treatments: the first was collected on d 8, and the second sample was taken on d 21. Samples were analyzed by Servi-Tech Laboratories, Dodge City, KS, for sodium, sulfate, total dissolved solids, pH, and several other minerals (Table 3).

Fecal samples were collected on d 5, 8, 15, and 21. The samples were collected from 2 randomly selected pigs per pen for a total of 14 samples per treatment. Immediately after collection, the samples were individually scored by 5 individuals trained to determine fecal consistency. In this way, 10 fecal consistency scores were determined for each pen, and an average score was reported for the pen. The scale used for assessing fecal consistency was based on a numerical scale from 1 to 5, where 1 represented a hard, dry fecal pellet; 2 represented a firmly formed feces; 3 represented soft, moist feces that retained its shape; 4 represented soft, unformed feces that assumed the shape of its container; and 5 represented a watery liquid that could be poured. After scoring, samples were analyzed for DM using a 2-stage DM procedure. The first stage consisted of drying the complete sample in a 122°F oven for 24 h. Afterward, the samples were cooled and ground into a powder. In the second stage, 1 g of the ground sample was placed in a crucible and dried in a 212°F oven for 24 h. The initial DM value was then multiplied by the second to determine a total percentage DM.

Nursery pig growth performance was analyzed as a 2 × 5 factorial with main effects of water and dietary treatment using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was designated as the experimental unit, and contrast statements were used to determine effects of water and dietary treatments and their interactions along with linear and quadratic effects of dietary zeolite. Results were considered significant at $P \le 0.05$ and a trend at $P \le 0.10$.

For fecal scores and fecal DM, repeated measures over time analysis was conducted using the MIXED procedure of SAS. Pen was the experimental unit and the fixed effects were water and dietary treatment. Contrast statements were used to evaluate: (1) linear and quadratic effects of increasing zeolite, (2) linear and quadratic effects over time (collection days), (3) water × day interactions, (4) diet × day interactions, and (5) water × diet × day interactions. Results were considered significant at $P \le 0.05$ and considered a trend at $P \le 0.10$.

Results and Discussion

For overall growth performance (d 0 to 21), a water source × diet interaction ($P < 0.01$) was observed for ADG and F/G (Table 4). The interaction occurred because pigs fed 1% HA had poorer ($P < 0.01$) ADG and F/G when drinking 2,000 ppm sodium sulfate water but improved ADG and F/G when drinking control water. Pigs consuming 1% HA also had decreased ($P = 0.03$) ADFI when drinking 2,000 ppm sodium sulfate water compared with control water. For main effects, pigs drinking 2,000 ppm sodium sulfate water had poorer ($P = 0.01$) ADG and F/G and a tendency ($P = 0.08$) for lower ADFI compared with pigs drinking control water. Dietary treatment did not affect growth performance criteria.

A water × day interaction was observed ($P < 0.01$) for fecal consistency scores because fecal scores decreased over time for pigs drinking 2,000 ppm sodium sulfate water (Table 5). This observation indicates that their feces became firmer over time compared with pigs drinking control water that had similar fecal scores throughout the length of the study.

We observed a tendency ($P = 0.10$) for a water × diet interaction for d 5 fecal scores because of the greater difference between fecal scores on control and high-sulfate water for pigs eating the diet with 1% HA compared with pigs consuming other diets. We observed a water × diet ($P < 0.01$) interaction on d 8, because pigs eating diets containing 1 or 2 % zeolite and 1% HFB had looser fecal samples ($P < 0.03$) if they were drinking 2,000 ppm sodium sulfate water compared with pigs on these same treatments drinking control water. Pigs drinking 2,000 ppm sodium sulfate had less firm ($P < 0.01$) fecal samples than pigs drinking control water. Diet did not influence ($P > 0.40$) overall fecal consistency scores.

A water × day interaction ($P < 0.01$) was observed for fecal DM (Table 6). Fecal DM increased over time for pigs drinking 2,000 ppm sodium sulfate water but remained similar throughout the study for pigs drinking control water.

A water × diet interaction was observed ($P < 0.01$) on d 8, because pigs that ate diets with 1 or 2% zeolite or 1% HFB had lower ($P < 0.04$) fecal DM if they drank 2,000 ppm sodium sulfate water than pigs eating the same diets and drinking control water. Pigs on the control diet had similar fecal DM on both water sources. For main effects, pigs drinking 2,000 ppm sodium sulfate water had lower fecal DM ($P < 0.01$) on d 5, d 8, and for overall mean fecal DM. For diet effects, average fecal DM increased (linear, $P < 0.01$) with increasing zeolite inclusion, and pigs on control diets or 1% zeolite had lower ($P < 0.01$) or tended to have lower ($P = 0.06$) fecal DM than pigs consuming diets with 1% HFB.

Adding 2,000 ppm sodium sulfate within the water source had effects on fecal consistency similar to 3,000 ppm sodium sulfate in previous work. A significant impact on growth performance was observed at 2,000 ppm. This study agrees with Flohr et al. (2011), indicating that when providing high-sulfate containing water to newly weaned pigs, the largest detrimental effects occur within the first wk to 10 d after weaning.

Dietary regimen appeared to have no direct impact on growth performance regardless of which additive was used. The interactions between water and diet were mainly driven by the 1% HA diet, because these pigs had more fluid feces and poorer growth performance when supplemental sulfate was provided in the water treatment. A linear improvement in fecal DM was observed with increasing dietary zeolite, but there was no indication that these feed additives improved growth performance or led to firmer feces with less signs of diarrhea. This study contrasts with the previous work (Flohr et al., 2011), which showed that increasing zeolite up to 1% increased ADG and ADFI in nursery pigs.

Because of the variable responses found in studies conducted with zeolite, this additive may not be beneficial for growth performance in swine diets. Humic substances appeared to have no direct effect on growth performance or fecal consistency in this study, and some evidence indicated that they may be detrimental, which could be due to the fact that 1% may be above the optimal inclusion rate in swine diets. Research with other nutritional therapies in sulfate challenges may lead to effective practices to reduce scouring in early nursery pigs.

Table 1. Analyzed composition of feed additives

Item	Zeolite[1]	Humic acid[2]	Humic fulvic blend[3]
Element			
Ca, %	2.40	0.47	0.63
P, %	0.01	0.02	0.03
K, %	1.20	0.07	0.36
Na, %	0.10	0.20	0.42
Zn, ppm	59	101	72
Cu, ppm	10	20	16
Mn, ppm	---	14	166
Fe, ppm	6,000	6,000	14,000
Mg, ppm	9,000	600	2,500
Al, ppm	31,000	125,000	384,000
Si, ppm	329,000	---	---
Humic acid, %	---	55.70	26.80

[1] Chemical composition was performed by use of x-ray fluorescence and conducted at St. Cloud Mining Co., Truth or Consequences, NM.
[2] DPX 5800, Humatech Inc., Houston, TX. Analysis conducted by A & L Agricultural Laboratories Inc. Lubbock, TX (values reported on DM basis).
[3] DPX 9902, Humatech Inc., Houston, TX. Analysis conducted by A & L Western Agricultural Laboratories Inc., Modesto, CA (values reported on DM basis).

Table 2. Diet composition (as-fed basis)

Item	Phase 1[1]	Phase 2[2]
Ingredient, %		
Corn	38.16	57.06
Soybean meal (46.5% CP)	16.99	25.90
Dried distillers grains with solubles	5.00	---
Spray-dried animal plasma	4.00	---
Select menhaden fish meal	---	4.50
Spray-dried blood cells	1.25	---
Spray-dried whey	25.00	10.00
DPS 50[3]	3.00	---
Soybean oil	3.00	---
Monocalcium P (21% P)	0.85	0.38
Limestone	0.85	0.58
Salt	0.30	0.30
Zinc oxide	0.39	0.25
Trace mineral premix	0.15	0.15
Vitamin premix	0.25	0.25
L-lysine HCl	0.20	0.25
DL-methionine	0.13	0.13
L-threonine	0.08	0.11
Phytase[4]	0.13	0.17
Acidifier[5]	0.20	---
Vitamin E, 20,000 IU	0.05	---
Choline chloride 60%	0.04	---
Zeolite (clinoptilolite)[6]	---	---
Humic acid[7]	---	---
Humic and fulvic acid blend[8]	---	---
Total	100	100

continued

Table 2. Diet composition (as-fed basis)

Item	Phase 1[1]	Phase 2[2]
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.35	1.30
Isoleucine:lysine	54	61
Leucine:lysine	132	127
Methionine:lysine	30	35
Met & Cys:lysine	57	59
Threonine:lysine	65	63
Tryptophan:lysine	18	17
Valine:lysine	72	68
Total lysine, %	1.51	1.43
CP, %	21.6	21.3
ME, kcal/lb	1,552	1,505
Ca, %	0.75	0.70
P, %	0.73	0.63
Available P, %	0.65	0.47
Na, %	0.75	0.25
K, %	1.07	0.97
Added trace minerals, ppm[9]		
Zn	2,973	1,965
Fe[10]	165	165
Mn	40	40
Cu	17	17
I	0.30	0.30
Se	0.30	0.30

[1] Phase 1 diets were fed in pellet form from d 0 to 8.
[2] Phase 2 diets were fed in meal form from d 8 to 21.
[3] Nutra-Flo Company, Souix City, IA.
[4] Natuphos 600, BASF, Florham Park, NJ. Provided 354 and 446 phytase units (FTU)/lb of diet, respectively.
[5] Kem-gest, Kemin Industries Inc., Des Moines, IA.
[6] Zeolite, St Cloud Mining Company, Truth or Consequences, NM. Replaced corn to provide 1 and 2% zeolite.
[7] DPX 5800, Humatech Inc., Houston, TX.
[8] DPX 9902, Humatech Inc., Houston, TX.
[9] Total supplemental trace mineral content from feed additive and trace mineral premix was calculated within each respective dietary regimen.
[10] Added iron levels were 165, 6,165, 12,330, 6,165, and 14,165 ppm for control, 1 or 2% zeolite, 1% HA, and 1% HFB, respectively.

Table 3. Water analysis[1,2]

Item, ppm	Control water	2,000 ppm sodium sulfate
Total dissolved solids	233	1,770
Sulfate (SO_4)	77	1,700
Sulfate Sulfur (SO_4-S)	26	565
Chloride (Cl)	51	39
Sodium (Na)	34	565
Calcium (Ca)	13	14
Magnesium (Mg)	10	10
Potassium (K)	6	6
Iron (Fe)	0.1	0.1
Manganese (Mn)	0.01	0.01
pH, units	8.8	8.7

[1] Samples collected on d 8 and 21 were analyzed and the average values were reported.
[2] Water analysis performed by Servi-Tech Laboratories, Dodge City, KS.

Table 4. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig performance[1,2]

		d 0 to 21			Weight	
Water sodium sulfate, ppm	Dietary regimen	ADG, lb	ADFI, lb	F/G	Initial	Final
0	Control	0.59	0.82	1.4	12.5	25.4
	1% zeolite	0.60	0.82	1.36	12.5	25.2
	2% zeolite	0.55	0.77	1.4	12.5	24.2
	1% HA	0.66	0.85	1.29	12.5	26.5
	1% HFB	0.6	0.83	1.38	12.5	25.4
2,000	Control	0.58	0.81	1.41	12.5	25.3
	1% zeolite	0.55	0.78	1.44	12.5	24.3
	2% zeolite	0.58	0.78	1.36	12.5	24.7
	1% HA	0.51	0.75	1.51	12.6	23.2
	1% HFB	0.56	0.80	1.44	12.5	24.7
SEM		0.030	0.031	0.043	---	0.63
		Probability, *P*<				
Interactions						
Sulfate × diet		0.02	0.41	0.03	---	0.03
Sulfate within control		0.80	0.76	0.82	---	0.91
Sulfate within 1% zeolite		0.16	0.31	0.20	---	0.27
Sulfate within 2% zeolite		0.43	0.70	0.44	---	0.57
Sulfate within 1% HA		0.01	0.03	0.01	---	0.01
Sulfate within 1% HFB		0.28	0.45	0.32	---	0.40
Main effects						
Sulfate		0.01	0.08	0.01	---	0.02
Diet		0.91	0.54	0.95	---	0.64
Diet comparisons						
Zeolite linear		0.37	0.12	0.48	---	0.14
Zeolite quadratic		0.94	0.90	0.88	---	0.84
Control vs. 1% HA		0.92	0.59	0.84	---	0.41
Control vs. 1% HFB		0.88	0.90	0.99	---	0.69
1% zeolite vs. 1% HA		0.78	0.90	0.99	---	0.95
1% zeolite vs. 1% HFB		0.81	0.58	0.82	---	0.61
1% HA vs. 1% HFB		0.96	0.67	0.83	---	0.67

[1] A total of 350 weanling pigs (PIC 1050 barrows, initially 12.5 lb and 21 d of age) were used with 5 pigs per pen and 7 pens per treatment.

[2] Overall interactions of water and diet were analyzed and contrast statements were used to compare water treatment means within each dietary treatment.

Table 5. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig fecal consistency[1,2,3]

		Day of collection				
Water sodium sulfate, ppm	Dietary regimen	5	8	15	21	Mean
0	Control	3.4	3.3	3.4	3.4	3.4
	1% zeolite	3.4	2.8	3.3	3.4	3.2
	2% zeolite	3.5	2.7	3.1	3.4	3.2
	1% HA	3.3	3.1	3.3	3.4	3.3
	1% HFB	3.4	3.1	3.2	3.4	3.3
2,000	Control	3.7	3.3	3.3	3.4	3.4
	1% zeolite	3.8	3.7	3.4	3.4	3.6
	2% zeolite	3.7	3.4	3.4	3.3	3.4
	1% HA	3.8	3.3	3.3	3.5	3.5
	1% HFB	3.6	3.5	3.4	3.6	3.5
SEM		0.15	0.15	0.15	0.15	0.08
		Probability, *P*<				
Interactions						
Sulfate × diet		0.10	0.01	0.83	0.97	0.23
Sulfate within control		0.13	0.83	0.42	0.69	0.78
Sulfate within 1% zeolite		0.06	0.01	0.65	0.96	0.01
Sulfate within 2% zeolite		0.28	0.01	0.23	0.71	0.01
Sulfate within 1% HA		0.01	0.21	0.93	0.74	0.03
Sulfate within 1% HFB		0.30	0.03	0.16	0.28	0.01
Main effects						
Sulfate		0.01	0.01	0.30	0.79	0.01
Diet		0.99	0.40	0.95	0.88	0.58
Diet comparisons						
Zeolite linear		0.85	0.09	0.48	0.73	0.20
Zeolite quadratic		0.82	0.43	0.65	0.63	0.33
Control vs. 1% HA		0.98	0.55	0.76	0.64	0.81
Control vs. 1% HFB		0.88	0.94	0.76	0.52	0.96
1% zeolite vs. 1% HA		0.76	0.66	0.73	0.82	0.67
1% zeolite vs. 1% HFB		0.66	0.92	0.73	0.69	0.89
1% HA vs. 1% HFB		0.90	0.59	0.99	0.87	0.77

[1] A total of 560 fecal samples were collected (140 per collection day; fecal samples were collected on d 5, 8, 15, and 21). Two samples were taken per pen and scored by 5 trained individuals; those 10 scores were then averaged and reported as pen means for each collection day.
[2] Scoring scale guidelines: 1 = dry, firm pellet; 2 = firmly formed stool; 3 = soft stool that retains shape; 4 = soft, unformed stool that takes shape of container; 5 = watery liquid that can be poured.
[3] Water × diet × day interaction ($P = 0.45$), water × day interaction ($P < 0.01$), diet × day ($P = 0.99$), day effect ($P < 0.01$).

Table 6. Influence of dietary natural zeolite or humic acid substances (HA and HFB) and high-sulfate water on nursery pig fecal DM[1,2,3]

		Day of collection				
Water sodium sulfate, ppm	Dietary regimen	5	8	15	21	Mean
0	Control	20.5	23.1	22.7	26.0	23.1
	1% zeolite	21.6	26.7	23.8	25.2	24.3
	2% zeolite	23.1	28.7	26.7	27.1	26.4
	1% HA	23.2	25.6	24.6	27.5	25.2
	1% HFB	22.7	26.5	26.9	26.8	25.7
2,000	Control	18.3	22.3	23.8	26.5	22.7
	1% zeolite	19.4	18.8	24.6	27.0	22.5
	2% zeolite	20.5	22.1	24.8	27.4	23.7
	1% HA	18.3	22.7	25.1	25.3	22.8
	1% HFB	20.7	22.0	24.9	28.3	24.0
SEM		1.70	1.70	1.70	1.70	0.92
		Probability, $P<$				
Interactions						
Sulfate × diet		0.19	0.01	0.73	0.93	0.60
Sulfate within control		0.32	0.70	0.63	0.82	0.74
Sulfate within 1% zeolite		0.30	0.01	0.69	0.42	0.08
Sulfate within 2% zeolite		0.24	0.01	0.38	0.88	0.01
Sulfate within 1% HA		0.03	0.19	0.83	0.32	0.03
Sulfate within 1% HFB		0.35	0.04	0.36	0.48	0.11
Main effects						
Sulfate		0.01	0.01	0.76	0.70	0.01
Diet		0.50	0.35	0.40	0.84	0.02
Diet comparisons						
Zeolite linear		0.12	0.08	0.11	0.52	0.01
Zeolite quadratic		0.94	0.34	0.83	0.61	0.38
Control vs. 1% HA		0.38	0.36	0.31	0.93	0.15
Control vs. 1% HFB		0.13	0.31	0.09	0.40	0.01
1% zeolite vs. 1% HA		0.86	0.39	0.68	0.84	0.41
1% zeolite vs. 1% HFB		0.42	0.34	0.28	0.34	0.06
1% HA vs. 1% HFB		0.54	0.95	0.51	0.46	0.30

[1] A total of 560 fecal samples were collected (140 per collection day; fecal samples were collected on d 5, 8, 15, and 21). Two samples were taken per pen and were scored by 5 trained individuals; those 10 scores were then averaged and reported as pen means for each collection day.

[2] Scoring scale guidelines: 1 = dry, firm pellet; 2 = firmly formed stool; 3 = soft stool that retains shape; 4 = soft, unformed stool that takes shape of container; 5 = watery liquid that can be poured.

[3] Water × diet × day interaction ($P = 0.69$), water × day interaction ($P < 0.01$), diet × day ($P = 0.99$), day effect ($P < 0.01$).

Evaluation of Novel Enzyme Blend on Nursery Pig Performance[1]

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Summary

Two experiments were conducted to determine the effects of a dietary enzyme blend and diet complexity on weanling pig performance. In Exp. 1, 180 pigs (initially 12.7 lb BW and 21 d of age) were used in an 18-d growth trial. Pigs were blocked by weight and randomly allotted to 1 of 3 dietary treatments with 5 pigs per pen and 12 pens per treatment. The 3 dietary treatments included (1) a high-complexity positive control, (2) a low-complexity negative control, and (3) a treatment with an added proprietary enzyme blend (Engrain LLC, Manhattan, KS). All diets were fed in 2 phases, with pigs fed a Phase 1 pelleted diet from d 0 to 8 and a Phase 2 diet in meal form from d 9 to 18. From d 0 to 8, pigs fed the high-complexity diet had improved ($P < 0.05$) ADG and F/G compared with pigs fed the low-complexity diet without enzymes. Also, pigs fed the low-complexity diet with enzymes tended to have increased ($P < 0.10$) ADG and improved ($P < 0.05$) F/G compared with pigs fed the low-complexity diet without enzymes. From d 9 to 18, no differences were observed in growth among pigs fed any of the dietary treatments. Overall (d 0 to 18), pigs fed the high-complexity diet had improved ($P < 0.05$) F/G compared with pigs fed the low-complexity diet with or without enzymes, but ADG and ADFI did not differ among the 3 dietary treatments.

In Exp. 2, 360 pigs (initially 12.4 lb BW and 21 d of age) were used in an 18-d growth trial. Pigs were blocked by weight and allotted to 1 of 6 dietary treatments with 5 pigs per pen and 12 pens per treatment. Dietary treatments were arranged in a 2 × 3 factorial with main effects of diet complexity (low, medium, or high) with or without the enzyme blend. Diets were fed in 2 phases, with pigs fed a Phase 1 pelleted diet from d 0 to 8 and a Phase 2 diet in meal form from d 9 to 18. Overall (d 0 to 18), pigs fed increasingly complex diets had improved ADG, ADFI, and F/G (linear, $P < 0.02$). Added dietary enzyme blend had no effects on pig growth performance. Thus, we conclude that diet complexity for the newly weaned pig is essential for improved performance postweaning; however, the enzyme blend evaluated in these experiments did not affect overall growth performance.

Key words: diet complexity, enzyme, nursery pig

Introduction

The use of dietary enzymes as a means of improving nutrient digestibility in weanling pigs continues to receive attention because of the increased price of feed ingredients. The majority of the research has focused on the use of enzymes in diets containing low-energy, high-fiber ingredients such as dried distillers grains with solubles and wheat

1 Appreciation is expressed to Engrain, LLC (Manhattan, KS) for partial funding of the experiments.
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middlings. These ingredients have a high concentration of non-starch polysaccharides that serve as substrates for the added dietary enzymes to break down.

Because weanling pigs have a relatively immature digestive system, adding enzymes to diets may make the diet more digestible. If added enzymes improve digestibility of the diet, the amount of specialty protein sources used in these diets could be reduced; thus, the objective of this study was to evaluate a novel proprietary enzyme blend fed in diets of varying complexity on weanling pig performance.

Procedures

All experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

A total of 180 pigs (PIC 1050; initially 12.7 lb and 21 d of age) were used in an 18-d growth trial. Pigs were blocked by weight and randomly allotted to 1 of 3 dietary treatments with 5 pigs per pen and 12 pens per treatment. Each pen (5 ft × 5 ft) contained a 4-hole dry self-feeder and a 1-cup waterer to provide ad libitum access to feed and water. The study was conducted at the Kansas State University Segregated Early Weaning Facility, Manhattan, KS.

The 3 dietary treatments included: (1) a high-complexity positive control diet, (2) a low-complexity negative control diet, and (3) the low-complexity diet (treatment 2) with an added enzyme blend (Engrain LLC, Manhattan, KS). All diets were fed in 2 phases with pigs fed a pelleted Phase 1 diet from d 0 to 8 and a Phase 2 diet in meal form from d 9 to 18 (Table 1). All diets contained 20% and 5% spray-dried whey for Phases 1 and 2, respectively. The highly complex diet included 6% spray-dried animal plasma, 1.25% spray-dried blood cells, and 1.25% select menhaden fish meal in Phase 1 and 1.25% spray-dried blood cells and 1.25% select menhaden fish meal in Phase 2; the low-complexity diets were not supplemented with these ingredients. All diets were manufactured at the Kansas State University Grain Science Feed Mill. Pigs were weighed and feed disappearance was measured on d 8 and 18 of the trial to determine ADG, ADFI, and F/G.

Experiment 2

A total of 360 pigs (PIC 1050; initially 12.4 lb and 21 d of age) were used in an 18-d growth trial. Pigs were housed in the same facility as Exp. 1.

At weaning, pigs were fed 1 of 6 dietary treatments arranged in a 2 × 3 factorial. Main effects included diet complexity (low, medium, or high) and presence or absence of enzyme blend (Engrain LLC, Manhattan, KS). All diets were fed in 2 phases, with pigs fed a Phase 1 pelleted diet from d 0 to 8 and a Phase 2 diet in meal form from d 9 to 18 (Tables 2 and 3). The high-complexity diet contained similar levels of specialty protein sources as in Exp. 1, with the medium-complexity diets containing half the amount of each specialty ingredient. The low-complexity diet contained no animal specialty protein sources in either phase. Similar to Exp. 1, all diets contained 20% and 5% spray-dried whey for Phases 1 and 2, respectively. All diets were manufactured at the K-State

Grain Science Feed Mill. Pigs were weighed and feed disappearance was measured on d 8 and 18 of the trial to determine ADG, ADFI, and F/G.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Data were analyzed using an analysis of variance using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with the weight block as a random effect and the treatments as fixed effects with linear and quadratic polynomials used to determine the effect of complexity in Exp. 2. Results were considered significant at $P \leq 0.05$ and were considered a trend at $P \leq 0.10$.

Results and Discussion

Experiment 1

From d 0 to 8, pigs fed the high-complexity diet had improved ($P < 0.05$) ADG compared with pigs fed the negative control diet, with pigs fed the negative control diet with added enzymes intermediate. No differences ($P > 0.10$) were observed in ADFI among treatments. No differences ($P > 0.10$) were observed in F/G between pigs fed the negative control diet with enzymes and pigs fed the high-complexity positive control diet, both of which were better than the negative control, low-complexity, diet. From d 9 to 18, ADG, ADFI, and F/G did not differ ($P > 0.10$) among treatments. Overall (d 0 to 18), there were no differences among pigs fed any of the dietary treatments; however, pigs fed the positive control diet had improved ($P < 0.05$) F/G compared with pigs fed the negative control diet with or without enzymes.

Experiment 2

From d 0 to 8, pigs fed increasingly complex diets had improved (linear, $P < 0.001$) ADG, ADFI, and F/G (Table 4). Adding the enzyme blend to any of the diets had no effect on pig performance ($P > 0.10$). From d 9 to 18, neither diet complexity nor added enzyme had an effect ($P > 0.10$). Overall (d 0 to 18), pigs fed increasingly complex diets had improved (linear, $P < 0.02$) ADG, ADFI, and F/G; again, adding an enzyme blend to any of the diets did not affect pig growth performance

Addition of the enzyme blend to low-complexity diets tended to improve ADG in Exp. 1, but not in Exp. 2. The reason for the inconsistency is unknown, because the facilities, pig source, health, and initial pig weight were similar for both experiments; however, these data demonstrate the importance of diet complexity immediately after weaning on nursery pig growth performance.

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

	Phase 1		Phase 2	
Item	Low complexity	High complexity	Low complexity	High complexity
Ingredient, %				
Corn	31.58	45.73	49.70	60.53
Soybean meal (46.5% CP)	40.00	17.51	38.75	25.01
Spray-dried animal plasma	-	6.00	-	.
Select menhaden fish meal	-	1.25	-	1.25
Spray-dried blood cells	-	1.25	-	1.25
Spray dried whey	20.00	20.00	5.00	5.00
Soybean oil	3.00	3.00	1.00	1.00
Monocalcium phosphate (21% P)	1.60	1.08	1.70	1.58
Limestone	0.70	0.95	0.85	0.85
Salt	0.30	0.30	0.30	0.30
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-lysine HCl	0.18	0.23	0.15	0.40
DL-methionine	0.17	0.18	0.10	0.20
L-threonine	0.08	0.07	0.06	0.19
L-tryptophan	-	-	-	0.02
L-isoleucine	-	0.06	-	0.04
Lactic acid	2.00	2.00	2.00	2.00
Engrain enzyme blend[2]	-	-	-	-
Total	100.0	100.0	100.0	100.0
Standard ileal digestible (SID) amino acids, %				
Lysine, %	1.45	1.45	1.32	1.32
Isoleucine:lysine, %	66%	55%	68%	55%
Methionine:lysine, %	34%	31%	32%	36%
Met & Cys:lysine, %	58%	58%	58%	58%
Threonine:lysine, %	63%	63%	63%	63%
Tryptophan:lysine, %	19%	17.6%	20%	17.1%
Valine:lysine, %	69%	69%	74%	66%
ME, kcal/lb	1,547	1,564	1,513	1,516
DE, kcal/lb	1,636	1,639	1,596	1,591
SID lysine:ME, g/Mcal	4.25	4.21	3.94	3.95
Total lysine, %	1.61	1.59	1.47	1.45
CP, %	24.2	21.6	23.3	20.1
Ca, %	0.86	0.86	0.82	0.82
P, %	0.85	0.77	0.81	0.76
Available P, %	0.55	0.55	0.47	0.47

[1] Pigs were fed Phase 1 diets from d 0 to 8 and Phase 2 diets from d 9 to 18.

[2] Added at a rate of 0.11% in low-complexity diets in Phase 1 and Phase 2.

Table 2. Composition of diets, Exp. 2 (as-fed basis)[1]

	Phase 1			Phase 2		
Item Diet complexity:	Low	Medium	High	Low	Medium	High
Ingredient, %						
Corn	32.56	39.55	46.71	50.69	56.11	61.51
Soybean meal (46.5% CP)	40.01	28.87	17.52	38.75	31.88	25.02
Spray-dried animal plasma	-	3.00	6.00	-	-	-
Select menhaden fish meal	-	0.63	1.25	-	0.63	1.25
Spray-dried blood cells	-	0.63	1.25	-	0.63	1.25
Spray dried whey	20.00	20.00	20.00	5.00	5.00	5.00
Soybean oil	3.00	3.00	3.00	1.00	1.00	1.00
Monocalcium phosphate (21% P)	1.60	1.35	1.08	1.70	1.65	1.58
Limestone	0.70	0.83	0.95	0.85	0.85	0.85
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.18	0.20	0.23	0.15	0.29	0.41
DL-methionine	0.17	0.17	0.18	0.10	0.15	0.20
L-threonine	0.08	0.08	0.07	0.05	0.13	0.19
L-tryptophan	-	-	-	-	-	0.02
L-isoleucine	-	-	0.07	-	-	0.04
Lactic acid	1.00	1.00	1.00	1.00	1.00	1.00
Engrain enzyme blend[2]	-	-	-	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0
Standard ileal digestible (SID) amino acids, %						
Lysine, %	1.45	1.45	1.45	1.32	1.32	1.32
Isoleucine:lysine, %	65	58	55	68	60	55
Methionine:lysine, %	34	32	31	32	34	36
Met & Cys:lysine, %	58	58	58	58	58	58
Threonine:lysine, %	63	63	63	63	63	63
Tryptophan:lysine, %	19	18	18	20	18	17
Valine:lysine, %	69	69	69	73	69	65
ME, kcal/lb	1,516	1,525	1,533	1,482	1,483	1,484
DE, kcal/lb	1,604	1,606	1,607	1,564	1,561	1,558
SID lysine:ME, g/Mcal	4.34	4.31	4.29	4.03	4.04	4.03
Total lysine, %	1.61	1.60	1.59	1.47	1.46	1.45
CP, %	24.0	22.8	21.4	23.1	21.5	20.0
Ca, %	0.86	0.86	0.86	0.82	0.82	0.82
P, %	0.84	0.81	0.76	0.80	0.78	0.75
Available P, %	0.55	0.55	0.55	0.47	0.47	0.47

[1] Pigs were fed Phase 1 diets from d 0 to 8 postweaning and phase 2 diets from d 8 to 18 postweaning.
[2] Included at a rate of 0.10% in each diet combination for a total of 6 treatments.

Table 3. Effects of Engrain enzyme on nursery pig growth performance (Exp. 1)[1]

	Low complexity	Low complexity + enzyme	High complexity	SEM
d 0 to 8				
ADG, lb	0.28[bx]	0.33[bcy]	0.37[cy]	0.020
ADFI, lb	0.33	0.34	0.36	0.017
F/G	1.25[b]	1.05[c]	0.99[c]	0.057
d 9 to 18				
ADG, lb	0.73	0.69	0.69	0.024
ADFI, lb	0.97	0.95	0.91	0.026
F/G	1.34	1.39	1.33	0.025
d 0 to 18				
ADG, lb	0.53	0.53	0.54	0.019
ADFI, lb	0.68	0.68	0.67	0.019
F/G	1.30[c]	1.29[c]	1.23[b]	0.023

[1] A total of 180 pigs (21 d of age and 12.7 lb) with 5 pigs per pen and 12 pens per treatment.
[b,c] Within a row, means without a common superscript differ ($P < 0.05$).
[x,y] Within a row, means without a common superscript differ ($0.05 < P < 0.10$).

Table 4. Effects of diet complexity and Engrain enzyme on growth performance of nursery pigs (Exp. 2)[1]

								Probability, $P<$		
Diet complexity:	Low		Medium		High			Complexity		
Item Enzyme:	No	Yes	No	Yes	No	Yes	SEM	Linear	Quadratic	Enzyme
d 0 to 8										
ADG, lb	0.30	0.30	0.35	0.37	0.38	0.38	0.019	0.0001	0.29	0.81
ADFI, lb	0.36	0.36	0.40	0.40	0.42	0.43	0.019	0.001	0.53	0.86
F/G	1.21	1.22	1.15	1.10	1.09	1.12	0.035	0.001	0.33	0.92
d 9 to 18										
ADG, lb	0.64	0.61	0.67	0.65	0.67	0.66	0.032	0.18	0.55	0.29
ADFI, lb	0.96	0.94	0.97	0.97	1.00	0.97	0.030	0.26	0.96	0.47
F/G	1.54	1.56	1.46	1.52	1.50	1.49	0.041	0.19	0.31	0.32
d 0 to 18										
ADG, lb	0.49	0.47	0.53	0.52	0.54	0.54	0.023	0.01	0.38	0.44
ADFI, lb	0.70	0.68	0.72	0.72	0.74	0.73	0.021	0.02	0.76	0.59
F/G	1.44	1.46	1.36	1.39	1.37	1.37	0.030	0.01	0.17	0.39

[1]A total of 360 pigs (21 d of age and 12.7 lb) were used, with 5 pigs per pen and 12 pens per treatment.

The Interactive Effects of Easyzyme and Phytase in Diets Containing High-Fiber Co-Products on Growth Performance of Nursery Pigs[1]

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Summary

Two experiments were conducted to determine the effects of a dietary non-starch polysaccharide enzyme (Easyzyme, Archer Daniels Midland Co., Decatur, IL) or phytase (Phyzyme, Danisco Animal Nutrition, St. Louis, MO) addition in corn-soybean meal or high-fiber diets on nursery pig growth performance. In Exp. 1, 192 nursery pigs (PIC 327 × 1050, initially 21.8 lb) were allotted to 1 of 4 dietary treatments arranged in a 2 × 2 factorial. Main effects were diet type (corn-soybean meal or corn-soybean meal plus 30% wheat middlings) with or without added dietary enzyme (Easyzyme Mixer 1, 1 lb/ton). Each experiment involved 6 pigs per pen and 8 replications per treatment. All diets contained 340.5 phytase units (FTU)/lb. From d 0 to 21, pigs fed corn-soybean meal diets had greater ($P < 0.001$) ADG than those fed diets containing 30% wheat midds. Added Easyzyme had no effect on ADG. ADFI and F/G exhibited a diet type × Easyzyme interaction ($P < 0.03$). In corn-soybean meal diets, Easyzyme had no effect on ADFI or F/G, whereas in diets containing 30% wheat midds, Easyzyme increased ADFI and worsened F/G.

In Exp. 2, 350 nursery pigs (PIC 1050, initially 25.5 lb) were allotted to 1 of 7 dietary treatments arranged in a 2 × 3 factorial plus control. Pigs were fed either a corn-soybean meal–based diet with no Easyzyme or phytase (Phyzyme) or 1 of 6 diets containing 10% wheat midds, 10% hominy, and 10% corn germ meal with or without Easyzyme and 0, 500, or 1,200 FTU/kg phytase. In this experiment, available P was formulated to the pig's requirement before adding phytase to determine if it affected the digestibility of other nutrients that might enhance growth performance. In the experiment with 5 pigs per pen and 10 replications per treatment, from d 0 to 21, pigs fed the control corn-soybean meal–based diet had greater ADG, ADFI, and better F/G than pigs fed co-product-based diets. Added Easyzyme had no effect on ADG and ADFI, but worsened F/G. Increasing phytase had no effect on ADG, ADFI, or F/G. These results suggest that adding high-fiber co-products to diets decreased ADG and worsened F/G compared with corn-soybean meal diets. Added Easyzyme or high concentrations of phytase in diets adequate in P had no positive effects on growth performance.

Key words: by-products, enzyme, fiber, phytase, nursery pig

[1] Appreciation is expressed to Archer Daniels Midland Co., Decatur, IL, for providing the Easyzyme used in these experiments and for partial financial support.

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Introduction

Co-product ingredients are increasingly used to reduce ever-rising feed costs. Diet formulation must account for the fact that most co-product ingredients are higher in fiber and lower in energy than corn (corn ME = 1,551 kcal/lb; wheat middlings ME = 1,372 kcal/lb; NRC, 1998[3]). Wheat middlings (midds), a co-product of wheat milling, are often used in swine diets, but the high fiber concentration in wheat midds has proven to have negative effects on growth performance in the nursery. In a recent study, increasing wheat midds decreased ADG as a result of decreased ADFI (De Jong et al., 2011[4]).

Because of the high fiber in diets containing wheat midds, supplemental enzymes are often added to the diet in hopes of making the fiber more digestible and improving growth performance. A recent hypothesis is that added phytase in diets already adequate in available P could potentially increase digestibility of nutrients other than P.

The objective of these experiments was to compare growth performance of pigs fed corn-soybean meal–based diets to those fed diets containing high levels of co-product ingredients with or without the addition of a dietary non-starch polysaccharide enzyme (Easyzyme, Archer Daniels Midland Co., Decatur, IL) or supplemental phytase (Phyzyme, Danisco Animal Nutrition, St. Louis, MO).

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. Experiment 1 was conducted at the Kansas State University Swine Teaching and Research Center, and Exp. 2 was conducted at the K-State Segregated Early Weaning Facility, Manhattan, KS.

In Exp. 1, a total of 192 nursery pigs (PIC 327 × 1050, initially 21.8 lb and 35 d of age) were used in a 21-d trial to determine the effects of a dietary non-starch polysaccharide enzyme, Easyzyme, in corn-soybean meal or high-fiber diets on nursery pig growth performance. After weaning, pigs were fed common pretest diets for 15 d. Pens of pigs were then allotted to 1 of 4 dietary treatments with 6 pigs per pen and 8 replications per treatment. Each pen (5 ft × 5 ft) had metal slatted floors, one 5-hole self-feeder, and a nipple waterer. Throughout the study, the pigs had ad libitum access to feed and water.

The dietary treatments were arranged in a 2 × 2 factorial with main effects of diet type (corn-soybean meal vs. corn-soybean meal plus 30% wheat midds) with or without Easyzyme (Table 1). All diets contained phytase at 340.5 FTU/lb of complete diet. All pigs and feeders were weighed on d 0, 7, 14, and 21 to determine ADG, ADFI, and F/G.

In Exp. 2, the objective was not only to evaluate Easyzyme in high-co-product diets, but also to examine the effects of superdosing phytase in diets with adequate available P. A total of 350 nursery pigs (PIC 1050, initially 25.5 lb and 42 d of age) were used in a 21-d trial to determine the effects of Easyzyme and Phyzyme addition in corn-soybean meal or high-fiber co-product diets on nursery pig growth performance. Pigs were fed

[3] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.
[4] De Jong et al., Swine Day 2011, Report of Progress 1056, pp. 114.

either a corn-soybean meal–based diet with no Easyzyme or Phyzyme or 1 of 6 diets containing 10% wheat midds, 10% hominy, and 10% corn germ meal with or without Easyzyme and 0, 500, or 1,200 FTU/kg phytase (Table 2). The assigned ME energy values in diet formulation for wheat midds, hominy, and corn germ meal were 1,372, 1,456, and 1,399 kcal/lb, respectively. Hominy and corn germ meal were provided by Archer Daniels Midland.

After arrival at the nursery, pigs were fed common pretest diets for 21 d. Pens of pigs were then allotted to 1 of 7 dietary treatments with 5 pigs per pen and 10 replications per treatment. Each pen (4 ft × 5 ft) had slatted floors, one 5-hole self-feeder, and a nipple waterer. Throughout the study, the pigs had ad libitum access to feed and water.

Data were analyzed in a completely randomized design with pen as the experimental unit. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Exp. 1 evaluated main effects of diet type and added Easyzyme and their interaction. In Exp. 2, contrasts were made to compare diet type (corn-soybean meal vs. high-fiber co-product diets), then main effects of added Easyzyme and increasing Phyzyme and their interaction were evaluated within the high-fiber co-product diets.

Results and Discussion

In Exp. 1, pigs fed the corn-soybean meal–based diet had 8% greater ($P < 0.001$) ADG than pigs fed the diets with 30% wheat midds (Table 3). This ADG response is consistent with the findings of De Jong et al. (2011[4]), who observed a 6% decrease in ADG with the addition of 20% wheat midds. In the present study, there was a diet type × enzyme interaction ($P < 0.03$) for ADFI and F/G. In pigs fed the corn-soybean meal diet, addition of Easyzyme had no effect on ADFI or F/G, but in pigs fed diets with 30% wheat midds, added Easyzyme increased ADFI and worsened F/G. Jones et al. (2010[5]) observed no improvement in pig growth performance when diets contained 30% dried distillers grains with solubles (DDGS) with or without Easyzyme, the same enzyme used in this experiment. Jacela et al. (2010[6]) also observed no beneficial effects on pig growth or feed efficiency for a variety of dietary enzymes in either corn- or corn-DDGS–based diets.

For Exp. 2, similar to Exp. 1, pigs fed the corn-soybean meal–based diet had 9% greater ADG and 6% better F/G ($P < 0.001$) than pigs fed the co-product-based diet (Tables 4 and 5), and added Easyzyme had no effect on ADG or ADFI but worsened ($P < 0.001$) F/G.

Added phytase improves the digestibility of phytate P in feed ingredients for swine and poultry. In addition, phytase may improve the digestibility of other nutrients in the diet. The diets in Exp. 2 were adequate in P; therefore, the objective was to determine if

[5] Jones, C. K., J. R. Bergstrom, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, J. L. Nelssen, and S. S. Dritz. 2010. Efficacy of commercial enzymes in diets containing a variety of levels and sources of dried distillers grains with solubles for nursery pigs. J. Anim Sci. 88:2084–2091.

[6] Jacela, J. Y., S. S. Dritz, J. M. DeRouchey, M. D. Tokach, R. D. Goodband, and J. L. Nelssen. 2010. Effects of supplemental enzymes in diets containing dried distillers grains with solubles on finishing pig growth performance. Prof. Anim. Sci. 26:425–434.

high levels of phytase might positively affect pig performance. In this study, increasing added phytase had no effect on ADG or F/G (Table 6).

In conclusion, with the high-fiber co-product diets used in these experiments, neither Easyzyme nor added phytase improved pig performance.

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

Item	Corn-soybean meal	30% wheat middlings
Ingredient %		
Corn	63.74	41.17
Soybean meal, 46.5% CP	32.79	25.41
Wheat middlings	---	30.00
Monocalcium P, 21% P	1.05	0.60
Limestone	0.95	1.20
Salt	0.350	0.35
Vitamin premix	0.250	0.25
Trace mineral premix	0.150	0.15
L-lysine HCl	0.330	0.45
DL-methionine	0.14	0.14
L-threonine	0.13	0.17
Phytase 600[2]	0.13	0.13
Easyzyme Mixer 1[3]	---	---
Total	100	100
Calculated analysis		
Standard ileal digestible (SID) amino acids, %		
Lysine	1.28	1.28
Isoleucine:lysine	61	57
Leucine:lysine	129	117
Methionine:lysine	34	33
Met & Cys:lysine	58	58
Threonine:lysine	63	63
Tryptophan:lysine	17	17
Valine:lysine	68	66
Total lysine, %	1.42	1.40
ME, kcal/lb	1,504	1,455
SID lysine:ME, g/Mcal	3.86	3.99
CP, %	21.15	20.71
Ca, %	0.69	0.70
P, %	0.63	0.70
Available P, %	0.42	0.42

[1] Treatment diets fed for 21 d.

[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

[3] Easyzyme Mixer 1 (Archer Daniels Midland Company, Decatur, IL) was added to the diet in place of corn at a rate of 1lb/ton.

Table 2. Composition of diets, Exp. 2 (as-fed basis)[1]

Item	Corn-soy	High fiber co-products
Ingredient, %		
Corn	62.05	26.65
Soybean meal, 46.5% CP	33.95	29.45
Hominy feed	---	10.00
Wheat middlings	---	20.00
Corn germ	---	10.00
Monocalcium P, 21% P	1.65	1.15
Limestone	1.20	1.45
Salt	0.35	0.35
Vitamin premix	0.15	0.15
Trace mineral premix	0.15	0.15
L-lysine HCl	0.30	0.38
DL-methionine	0.13	0.15
L-threonine	0.12	0.15
Phytase 600[2]	---	---
Easyzyme Mixer 1[3]	---	---
Total	100	100
Calculated analysis		
Standard ileal digestible (SID) amino acids, %		
Lysine, %	1.28	1.28
Isoleucine:lysine	63	59
Leucine:lysine	130	116
Methionine:lysine	33	34
Met & Cys:lysine	58	58
Threonine:lysine	63	63
Tryptophan:lysine	18	18
Valine:lysine	69	1
Total lysine, %	1.42	1.48
ME, kcal/lb	1,493	1,438
SID lysine:ME ratio, g/Mcal	3.89	4.04
CP, %	21.50	22.20
Ca, %	0.90	0.90
P, %	0.75	0.87
Available P, %	0.42	0.42

[1] Treatment diets fed for 21 d.
[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) was added in place of corn to provide either 500 or 1200 phytase units (FTU)/kg phytase.
[3] Easyzyme Mixer 1 (Archer Daniels Midland Co., Decatur, IL) was added in place of corn at a rate of 1lb/ton.

Table 3. Effects of wheat middlings and Easyzyme on nursery pig performance (Exp. 1)[1]

	Corn-soybean meal		30% wheat midds					
Item Easyzyme:	No	Yes	No	Yes	SEM	Enzyme × diet type	Enzyme	Diet type
Initial wt, lb	21.85	21.84	21.82	21.81	0.34	1.00	0.99	0.93
d 0 to 21								
ADG, lb	1.19[b]	1.21[b]	1.12[a]	1.10[a]	0.02	0.34	1.00	0.0003
ADFI, lb	1.92[a]	1.88[a]	1.89[a]	2.03[b]	0.04	0.03	0.18	0.14
F/G	1.61[ab]	1.55[a]	1.69[b]	1.85[c]	0.04	0.01	0.15	0.001
Final wt, lb	46.87	47.33	45.33	44.86	0.62	0.46	0.99	0.003

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

[1] A total of 192 pigs (PIC 327 × 1050, initially 21.83 lb BW and 35 d of age) were used in a 21-d growth trial with 6 pigs per pen and 8 replications per treatment.

Table 4. Effects of high-fiber co-products, phytase, and Easyzyme on nursery pig performance (Exp. 2)[1]

	Corn-soy diet	Co-product diet												
	No phytase	No phytase		500 FTU[2]/kg phytase		1,200 FTU/kg phytase			Enzyme × phytase			Enzyme	Phytase	
Item Easyzyme:	No	No	Yes	No	Yes	No	Yes	SEM	Linear	Quadratic	Diet type	effect	Linear	Quadratic
Initial wt, lb	25.79	25.28	25.20	25.75	25.76	25.78	25.20	0.53	0.62	0.75	0.61	0.61	0.70	0.37
d 0 to 21														
ADG, lb	1.22	1.12	1.12	1.11	1.11	1.17	1.09	0.03	0.20	0.62	0.004	0.39	0.69	0.61
ADFI, lb	1.91	1.85	1.89	1.82	1.90	1.85	1.86	0.06	0.67	0.49	0.34	0.22	0.80	0.87
F/G	1.57	1.66	1.69	1.64	1.72	1.59	1.71	0.03	0.08	0.80	0.001	0.001	0.41	0.50
Final wt, lb	51.38	48.30	48.24	49.52	48.90	50.25	48.33	1.15	0.41	0.91	0.05	0.36	0.40	0.61

[1] A total of 350 pigs (PIC 1050, initially 25.53 lb BW and 42 d of age) were used in a 21-d growth trial with 5 pigs per pen and 10 replications per treatment.

[2] FTU: phytase units.

Table 5. Main effects of Easyzyme inclusion in high-fiber co-product nursery diets (Exp. 2)[1]

	Easyzyme[2]			
Item	No	Yes	SEM	*P*-value
Initial wt, lb	25.60	25.38	0.30	0.64
ADG, lb	1.13	1.11	0.02	0.37
ADFI, lb	1.84	1.89	0.05	0.24
F/G	1.63	1.70	0.02	0.001
Final wt, lb	49.36	48.49	0.66	0.38

[1] A total of 350 pigs (PIC 1050, initially 25.53 lb BW and 42 d of age) were used in a 21-d growth trial with 5 pigs per pen and 10 replications per treatment.
[2] Easyzyme Mixer 1 (Archer Daniels Midland Company, Decatur, IL) was added in place of corn at a rate of 1 lb/ton.

Table 6. Main effects of added phytase in high-fiber nursery diets (Exp. 2)[1]

	Phytase, FTU/kg[2]				Probability, *P*<	
Item	0	500	1,200	SEM	Linear	Quadratic
Initial wt, lb	25.24	25.76	25.49	0.37	0.70	0.37
ADG, lb	1.12	1.11	1.13	0.02	0.69	0.61
ADFI, lb	1.87	1.86	1.86	0.05	0.80	0.87
F/G	1.67	1.68	1.65	0.03	0.41	0.50
Final wt, lb	48.27	49.21	49.29	0.81	0.40	0.61

[1] A total of 350 pigs (PIC 1050, initially 25.53 lb BW and 42 d of age) were used in a 21-d growth trial with 5 pigs per pen and 10 replications per treatment.
[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO.) was added in place of corn to provide either 500 or 1,200 phytase units (FTU)/kg phytase.

Effects of AV-E Digest and XFE Liquid Energy on Nursery Pig Performance[1]

W. Ying, J. M. DeRouchey, M. D. Tokach, S. S. Dritz[2], R. D. Goodband, and J. L. Nelssen

Summary

A total of 347 nursery pigs (PIC 1050, initially 11.0 lb) were used in a 44-d trial. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 8 dietary treatments with 9 replications per treatment. Pigs were fed in 3 dietary phases (Phase 1, d 0 to 9; Phase 2, d 9 to 23; and Phase 3, d 23 to 44). The 8 dietary treatments included: (1) control diet containing no specialty protein sources; (2) 7.1% PEP2+ in Phase 1 and no specialty protein sources in Phase 2 or Phase 3; (3) 7.1% PEP2+ and 3.75% spray-dried animal plasma (SDAP) in Phase 1, 3.8% PEP2+ in Phase 2, and no specialty protein sources in Phase 3; (4) 7.1% PEP2+, 3.75% SDAP, and 3% liquid energy in Phase 1; 3.8% PEP2+ and 3% liquid energy in Phase 2; and 3% liquid energy but no specialty protein sources in Phase 3; (5) 7.1% PEP2+, 3.75% SDAP, and 3% choice white grease (CWG) in Phase 1; 3.8% PEP2+ and 3% CWG in Phase 2; and 3% CWG but no specialty protein sources in Phase 3; (6) 12.5% AV-E Digest (AV-E) and 2.5% spray-dried blood cells (SDBC) in Phase 1, 7.5% AV-E in Phase 2, and 2.5% AV-E in Phase 3; (7) 12.5% AV-E, 2.5% SDBC, and 3% liquid energy in Phase 1; 7.5% AV-E and 3% liquid energy in Phase 2; and 2.5% AV-E and 3% liquid energy in Phase 3; and (8) 12.5% AV-E, 2.5% SDBC, and 3% CWG in Phase 1; 7.5% AV-E and 3% CWG in Phase 2; and 2.5% AV-E and 3% CWG in Phase 3.

From d 0 to 9, pigs fed diets containing liquid energy tended ($P < 0.08$) to have improved ADG compared with pigs fed diets without liquid energy. No other differences between protein or energy sources were found. From d 9 to 23, pigs fed diets containing AV-E had greater ADG ($P < 0.04$) and tended to have improved F/G ($P < 0.10$) compared with pigs fed diets containing PEP2+. Pigs fed CWG had better ($P < 0.01$) F/G than pigs fed liquid energy. From d 23 to 44, ADG and F/G were improved ($P < 0.01$) from feeding CWG. Also, pigs fed CWG tended ($P < 0.07$) to have greater ADG and better ($P < 0.001$) F/G than pigs fed liquid energy. Overall (d 0 to 44), pigs fed CWG had increased ADG and final BW ($P < 0.02$) and better F/G ($P < 0.001$) than pigs fed diets without an additional energy source. Also, pigs fed diets containing CWG had better ($P < 0.001$) F/G than pigs fed liquid energy. In conclusion, adding CWG to nursery diets improved performance, but liquid energy did not. Pigs fed AV-E had performance equal to pigs fed other specialty protein sources.

Key words: AV-E Digest, choice white grease, liquid energy, nursery pig

[1] Appreciation is expressed to XFE Products, Des Moines, IA for partial funding of the experiment.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Introduction

Increasing dietary energy from added fat consistently has been shown to improve ADG and feed efficiency during the middle to late nursery period, but increased cost of added fat means that alternatives are being sought to increase energy density at a lower cost. A recent product made available for swine producers, XFE Liquid Energy (XFE Products, Des Moines, IA), is an alcohol-based liquid product that is believed to have the potential to increase the dietary energy level economically. Recent studies at Kansas State University have found mixed results for liquid energy improving ADG but have not shown improvements in feed efficiency (Ying et al., 2011[3]). Further research is needed to determine if an energy response from liquid energy can be found in nursery pigs.

High-quality specialty protein sources are continually sought for starter diets to lower feed cost and replace common protein sources such as fish meal. Previous research has demonstrated that addition of PEP2+ (porcine intestinal mucosa that is co-dried with vegetable proteins; TechMix, LLC, Stewart, MN) as a specialty protein source had improved growth performance in Phase 2 nursery diets (Myers et al., 2009[4]) compared with those fed fishmeal. In addition, high-quality, low-ash poultry meal can be used as an animal protein replacement in nursery diets (Keegan et al., 2004[5]). Another specialty product, AV-E Digest (XFE Products, Des Moines, IA), a poultry-based co-product, has potential to be used as an alternative animal protein source for nursery pigs, but research is lacking. The objectives of this experiment were to: (1) compare the effects of choice white grease (CWG) and XFE Liquid Energy, and (2) evaluate AV-E Digest as a specialty protein source for nursery pigs.

Procedures

All experimental procedures were approved by the K-State Animal Care and Use Committee.

A total of 347 nursery pigs (PIC 1050, initially 11.0 lb) were used in 44-d trial. Pigs were randomly allotted to 1 of 8 treatments with 5 pigs per pen and 9 pens per treatment. The study was conducted at the K-State Segregated Early Weaning facility in Manhattan, KS. Each pen (5 ft × 5 ft) contained a 4-hole dry self-feeder and a 1-cup waterer to provide ad libitum access to feed and water.

The 8 dietary treatments included: (1) control diet containing no specialty protein sources; (2) 7.1% PEP2+ in Phase 1 and no special protein sources in Phase 2 or Phase 3; (3) 7.1% PEP2+ and 3.75% spray-dried animal plasma (SDAP) in Phase 1, 3.8% PEP2+ in Phase 2, and no specialty protein sources in Phase 3; (4) 7.1% PEP2+, 3.75% SDAP, and 3% liquid energy in Phase 1; 3.8% PEP2+ and 3% liquid energy in Phase 2; and 3% liquid energy but no specialty protein sources in Phase 3; (5) 7.1% PEP2+, 3.75% SDAP, and 3% choice white grease (CWG) in Phase 1; 3.8% PEP2+ and 3% CWG in Phase 2; and 3% CWG but no specialty protein sources in Phase 3; (6) 12.5% AV-E Digest (AV-E) and 2.5% spray-dried blood cells (SDBC) in Phase 1; 7.5% AV-E in Phase 2; and 2.5% AV-E in Phase 3; (7) 12.5% AV-E, 2.5% SDBC and 3% liquid

[3] Ying et al., Swine Day 2011. Report of Progress 1056, pp. 129–137.

[4] Myers et al., Swine Day 2009. Report of Progress 1020, pp. 90–95.

[5] Keegan, T. P., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, R. D. Goodband, and S. S. Dritz. 2004. The effects of poultry meal source and ash level on nursery pig performance. J. Anim. Sci. 82:2750–2756.

energy in Phase 1; 7.5% AV-E and 3% liquid energy in Phase 2; 2.5% AV-E and 3% liquid energy in Phase 3; and (8) 12.5% AV-E, 2.5% SDBC, and 3% CWG in Phase 1; 7.5% AV-E and 3% CWG in Phase 2; and 2.5% AV-E and 3% CWG in Phase 3. Diets were formulated to the recommended standardized ileal digestible (SID) lysine:ME ratios for respective pig weights (Tables 1, 2, and 3). The ME of liquid energy used in diet formulation was equal to that of CWG (3.62 Mcal/lb). Spray-dried whey was included at 25% and 10% in all Phase 1 and 2 diets, respectively. Phase 1 diets were fed in pelleted form and manufactured at the K-State Grain Science Feed Mill, and Phase 2 and 3 diets were fed in meal form and manufactured at the K-State Animal Science Feed Mill.

Pigs were weighed and feed disappearance was determined on d 0, 5, 9, 16, 23, 33, and 44 to calculate ADG, ADFI, and F/G.

Data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit for analysis. Contrast statements were used to test the main effect of liquid energy (treatments 3 and 6 vs. 4 and 7), CWG (treatments 3 and 6 vs. 5 and 8) or AV-E (treatments 3, 4, and 5 vs. 6, 7, and 8), and to make comparison between liquid energy and CWG (treatments 4 and 7 vs. 5 and 8). Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

From d 0 to 9, pigs fed liquid energy tended ($P < 0.08$) to have improved ADG compared with pigs fed diets without liquid energy (Table 4). Pigs fed PEP2+ as the only specialty protein source had lower ($P < 0.05$) ADG than pigs fed the diet with a combination of PEP2+, SDAP, and liquid energy and the diet containing AV-E, SDBC, and CWG. Pigs fed no specialty protein sources or PEP2+ as the only specialty protein source had worse ($P < 0.05$) F/G than pigs fed the diet with a combination of PEP2+, SDAP, and liquid energy and the diet containing AV-E, SDBC, and CWG. Pigs fed the combination of PEP2+ and SDAP had worse ($P < 0.05$) F/G than pigs fed combinations of PEP2+, SDAP, and liquid energy. No differences between protein source regime (SDAP-PEP2+ vs. Av-E-SDBC) or energy (CWG vs. liquid energy) source were found.

From d 9 to 23, pigs fed diets containing AV-E had greater ADG ($P < 0.04$) and tended to have improved F/G ($P < 0.10$) compared with pigs fed diets containing PEP2+. Pigs fed CWG had better ($P < 0.01$) F/G than that of pigs fed liquid energy. Pigs fed combinations of AV-E and CWG had greater ($P < 0.05$) ADG than pigs fed PEP2+ or pigs previously fed PEP2+ in Phase 1 and the control diet in Phase 2. Pigs fed AV-E-CWG had better ($P < 0.05$) F/G than pigs fed diets containing PEP2+, PEP2+-liquid energy, or AV-E-liquid energy.

From d 23 to 44, there was improvement ($P < 0.01$) in ADG and F/G from feeding CWG compared with pigs fed diets without an additional energy source. Also, pigs fed diets containing CWG tended ($P < 0.07$) to have greater ADG and better ($P < 0.001$) F/G than pigs fed diets containing liquid energy. Pigs fed diets containing CWG or AV-E-CWG had better ($P < 0.05$) ADG than pigs previously fed PEP2+ in Phase 2 and control diet in Phase 3. Pigs fed control diet for all 3 phases had greater ($P < 0.05$) ADFI than pigs fed CWG or pigs fed PEP2+ in Phase 2 and the control diet in Phase 3. Pigs fed CWG had improved ($P < 0.05$) F/G compared with pigs fed all other treatments except the treatment containing AV-E and CWG, which was intermediate. Also, pigs fed AV-E and CWG together had improved ($P < 0.05$) F/G compared with pigs fed the control (regardless of previous phase diet), AV-E, or AV-E-liquid energy diets. Finally, pigs fed the control diet in all three phases had worse ($P < 0.05$) F/G then all other treatments except those fed AV-E-liquid energy.

Overall (d 0 to 44), pigs fed diets with CWG had improved ADG ($P < 0.02$), final BW ($P < 0.02$) and F/G ($P < 0.001$) compared with pigs fed diets without an additional energy source. Also, pigs fed diets containing CWG had better ($P < 0.001$) F/G than pigs fed liquid energy. Pigs fed diets with a combination of AV-E and CWG had greater ($P < 0.05$) ADG and final BW than pigs fed diets containing PEP2+ in Phase 1, 2, and no specialty protein source in Phase 3. Pigs fed the control diet for all 3 phases had greater ($P < 0.05$) ADFI than pigs fed diets containing PEP2+ in Phase 1 and 2 and no specialty protein source in Phase 3. Pigs fed diets containing a combination of AV-E and CWG had better ($P < 0.05$) F/G than other treatments, except pigs fed PEP2+-CWG. Pigs fed the PEP2+-liquid energy treatment series or AV-E in each phase with no added energy source had better ($P < 0.05$) F/G than pigs fed control diets for all 3 phases.

For overall energy source conclusions, feeding nursery pigs CWG improved ADG and F/G as expected; however, growth performance was not affected by feeding liquid energy. Although the actual energy value of liquid energy is unknown, these data along with previous research shows that liquid energy cannot substitute for fat in nursery pig diets and maintain similar performance.

For overall protein source conclusions, these data indicate that AV-E is a potential replacement for other animal specialty proteins sources such as PEP2+ or fish meal (based on previous research indicating PEP2+ is comparable to fish meal) in nursery diets. More research is needed to validate AV-E as an SDAP replacement in Phase 1 diets.

Table 1. Composition of Phase 1 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	7.1% PEP2+[2]	7.1% PEP2+, 3.75% SDAP[3]	7.1% PEP2+, 3.75% SDAP, 3% liquid energy[4]	7.1% PEP2+, 3.75% SDAP, 3% CWG[5]	12.5% AV-E[6], 2.5% SDBC[7]	12.5% AV-E, 2.5% SDBC, 3% liquid energy	12.5% AV-E, 2.5% SDBC, 3% CWG
Ingredient, %								
Corn	39.80	41.20	45.75	40.80	40.80	41.10	37.70	37.70
Soybean meal, 46.5% CP	31.60	23.25	15.15	17.00	17.00	15.15	17.00	17.00
PEP2+	--	7.10	7.10	7.10	7.10	--	--	--
AV-E Digest	--	--	--	--	--	12.50	12.50	12.50
Spray-dried animal plasma	--	--	3.75	3.75	3.75			
Spray-dried blood cells	--	--	--	--	--	2.50	2.50	2.50
Spray-dried whey	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Choice white grease	--	--	--	--	3.00	--	--	3.00
Liquid energy	--	--	--	3.00	--	--	3.00	--
Monocalcium P, 21% P	0.88	0.80	0.58	0.58	0.58	0.10	0.10	0.10
Limestone	0.70	0.78	0.93	0.93	0.93	0.43	0.40	0.40
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.35	0.25	0.225	0.25	0.25	0.175	0.20	0.20
DL-methionine	0.215	0.205	0.185	0.21	0.21	0.16	0.19	0.19
L-threonine	0.155	0.125	0.09	0.11	0.11	0.10	0.12	0.12
L-valine	0.04	--	--	--	--	--	--	--
Phytase[8]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 1. Composition of Phase 1 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	7.1% PEP2+[2]	7.1% PEP2+, 3.75% SDAP[3]	7.1% PEP2+, 3.75% SDAP, 3% liquid energy[4]	7.1% PEP2+, 3.75% SDAP, 3% CWG[5]	12.5% AV-E[6], 2.5% SDBC[7]	12.5% AV-E, 2.5% SDBC, 3% liquid energy	12.5% AV-E, 2.5% SDBC, 3% CWG
Calculated analysis								
Standard ileal digestible (SID) amino acids								
Lysine, %	1.41	1.40	1.41	1.47	1.47	1.40	1.46	1.46
Isoleucine:lysine, %	59	60	55	55	55	55	55	55
Methionine:lysine, %	36	36	33	34	34	34	35	35
Met & cys:lysine, %	58	58	58	58	58	58	58	58
Threonine:lysine, %	64	64	64	64	64	64	64	64
Tryptophan:lysine, %	17	18	18	18	18	17	17	17
Valine:lysine, %	65	65	66	65	65	77	75	75
Total lysine, %	1.56	1.54	1.55	1.61	1.61	1.53	1.59	1.59
ME, kcal/lb	1,479	1,470	1,481	1,542	1,542	1,471	1,533	1,533
SID lysine:ME, g/Mcal	4.32	4.32	4.32	4.32	4.32	4.32	4.32	4.32
CP, %	21.7	21.9	21.4	21.9	21.9	22.8	23.3	23.3
Ca, %	0.73	0.74	0.74	0.74	0.74	0.74	0.74	0.74
P, %	0.69	0.68	0.66	0.65	0.65	0.63	0.63	0.63
Available P, %	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55

[1] A total of 347 nursery pigs were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 1 diets were fed from d 0 to 9.
[2] TechMix, LLC, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.
[3] SDAP: spray-dried animal plasma (AP920; APC, Inc., Ames, IA).
[4] XFE Products, Des Moines, IA.
[5] CWG: choice white grease.
[6] AV-E: AV-E Digest (XFE Products, Des Moines, IA).
[7] SDBC: spray-dried blood cells.(AP302G APC, Inc., Ames, IA).
[8] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 2. Composition of Phase 2 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	Control	3.8% PEP2+[2]	3.8% PEP2+, 3% liquid energy[3]	3.8% PEP2+, 3% CWG[4]	7.5% AV-E[5]	7.5% AV-E, 3% liquid energy	7.5% AV-E, 3% CWG
Ingredient, %								
Corn	54.60	54.60	53.80	48.60	48.60	50.90	45.75	45.75
Soybean meal, 46.5% CP	31.85	31.85	29.05	31.20	31.20	27.55	31.20	31.20
PEP2+	--	--	3.80	3.80	3.80	--	--	--
AV-E Digest	--	--	--	--	--	7.50	7.50	7.50
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Choice white grease	--	--	--	--	3.00	--	--	3.00
Liquid energy	--	--	--	3.00	--	--	3.00	--
Monocalcium P, 21% P	0.95	0.95	0.88	0.85	0.85	0.45	0.43	0.43
Limestone	0.80	0.80	0.83	0.83	0.83	0.58	0.58	0.58
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.35	0.35	0.25	0.255	0.255	0.175	0.185	0.185
DL-methionine	0.165	0.165	0.15	0.17	0.17	0.09	0.11	0.11
L-threonine	0.15	0.15	0.11	0.12	0.12	0.075	0.09	0.09
Phytase[6]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 2. Composition of Phase 2 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	Control	3.8% PEP2+[2]	3.8% PEP2+, 3% liquid energy[3]	3.8% PEP2+, 3% CWG[4]	7.5% AV-E[5]	7.5% AV-E, 3% liquid energy	7.5% AV-E, 3% CWG
Calculated analysis								
Standard ileal digestible (SID) amino acids								
Lysine, %	1.33	1.33	1.33	1.38	1.38	1.33	1.39	1.39
Isoleucine:lysine, %	60	60	62	62	62	66	66	66
Methionine:lysine, %	34	34	34	35	35	32	32	32
Met & Cys:lysine, %	58	58	58	58	58	58	58	58
Threonine:lysine, %	64	64	64	64	64	64	64	64
Tryptophan:lysine, %	17.2	17.2	18.1	18.1	18.1	18.4	18.3	18.4
Valine:lysine, %	65	65	68	68	68	75	73	73
Total lysine, %	1.47	1.47	1.47	1.53	1.53	1.47	1.53	1.53
ME, kcal/lb	1,493	1,493	1,489	1,551	1,551	1,491	1,551	1,553
SID lysine:ME, g/Mcal	4.04	4.04	4.05	4.04	4.04	4.05	4.05	4.05
CP, %	21.2	21.2	21.9	22.5	22.5	23.2	23.8	23.8
Ca, %	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
P, %	0.64	0.64	0.64	0.63	0.63	0.63	0.62	0.62
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1] A total of 347 nursery pigs were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 2 diets were fed from d 9 to 23.
[2] TechMix LLC, Stewart, MN, and Midwest Ag Enterprises, Marshall, MN.
[3] XFE Products, Des Moines, IA.
[4] CWG: choice white grease.
[5] AV-E: AV-E Digest (XFE Products, Des Moines, IA).
[6] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), provided 231 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 3. Composition of Phase 3 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	Control	Control	3% liquid energy[2]	3% CWG[3]	2.5% AV-E[4]	2.5% AV-E, 3% liquid energy	2.5% AV-E, 3% CWG
Ingredient, %								
Corn	65.45	65.45	65.45	60.70	60.70	65.35	60.45	60.45
Soybean meal, 46.5% CP	31.05	31.05	31.05	32.80	32.80	28.95	30.85	30.85
AV-E Digest	--	--	--	--	--	2.50	2.50	2.50
Choice white grease	--	--	--	--	3.00	--	--	3.00
Liquid energy	--	--	--	3.00	--	--	3.00	--
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	1.05	0.90	0.90	0.90
Limestone	0.90	0.90	0.90	0.88	0.88	0.83	0.80	0.80
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.36	0.36	0.36	0.375	0.375	0.34	0.35	0.35
DL-methionine	0.14	0.14	0.14	0.16	0.155	0.125	0.14	0.14
L-threonine	0.14	0.14	0.14	0.15	0.15	0.125	0.14	0.14
Phytase[5]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 3. Composition of Phase 3 diets (as-fed basis)[1]

	Treatment							
	1	2	3	4	5	6	7	8
Item	Control	Control	Control	3% liquid energy[2]	3% CWG[3]	2.5% AV-E[4]	2.5% AV-E, 3% liquid energy	2.5% AV-E, 3% CWG
Calculated analysis								
Standard ileal digestible (SID) amino acids								
Lysine, %	1.26	1.26	1.26	1.31	1.31	1.26	1.31	1.31
Isoleucine:lysine, %	60	60	60	59	59	61	60	60
Methionine:lysine, %	34	34	34	34	34	34	34	34
Met & Cys:lysine, %	58	58	58	58	58	58	58	58
Threonine:lysine, %	63	63	63	63	63	63	63	63
Tryptophan:lysine, %	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Valine:lysine, %	67	67	67	66	66	69	68	68
Total lysine, %	1.39	1.39	1.39	1.44	1.44	1.39	1.44	1.44
ME, kcal/lb	1,505	1,505	1,505	1,567	1,567	1,504	1,566	1,566
SID lysine:ME, g/Mcal	3.80	3.80	3.80	3.79	3.79	3.80	3.79	3.79
CP, %	20.5	20.5	20.5	21.0	21.0	20.8	21.3	21.3
Ca, %	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
P, %	0.62	0.62	0.62	0.62	0.62	0.61	0.61	0.61
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

[1] A total of 347 nursery pigs were used in a 44-d study with 5 pigs per pen and 9 replications per treatment. Phase 3 diets were fed from d 23 to 44.
[2] XFE Products, Des Moines, IA.
[3] CWG: choice white grease.
[4] AV-E: AV-E Digest (XFE Products, Des Moines, IA).
[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with a release of 0.10% available P.

Table 4. The effects of AV-E Digest and XFE Liquid Energy on nursery pig performance[1]

	Treatment									Probability, *P*<			
	1	2	3	4	5	6	7	8					
d 0 to 9:	Control	7.1% PEP2+	7.1% PEP2+, 3.75% SDAP[2]	7.1% PEP2+, 3.75% SDAP, 3% liquid energy	7.1% PEP2+, 3.75% SDAP 3% CWG[3]	12.5% AV-E[4], 2.5% SDBC[5]	12.5% AV-E, 2.5% SDBC, 3% liquid energy	12.5% AV-E, 2.5% SDBC, 3% CWG					
d 9 to 23:	Control	Control	3.8% PEP2+	3.8% PEP2+, 3% liquid energy	3.8% PEP2+, 3% CWG	7.5% AV-E	7.5% AV-E, 3% liquid energy	7.5% AV-E, 3% CWG					
Item d 23 to 44:	Control	Control	Control	3% liquid energy	3% CWG	2.5% AV-E	2.5% AV-E +3% liquid energy	2.5% AV-E +3% CWG	SEM	AV-E[6]	Liquid energy[7]	CWG[8]	Liquid energy vs. CWG[9]
d 0 to 9													
ADG, lb	0.24[ab]	0.23[a]	0.24[ab]	0.32[c]	0.27[ac]	0.27[ac]	0.27[ac]	0.30[bc]	0.04	0.93	0.08	0.23	0.55
ADFI, lb	0.26	0.25	0.24	0.28	0.26	0.27	0.26	0.27	0.04	0.59	0.44	0.55	0.85
F/G	1.16[a]	1.09[ab]	1.00[ab]	0.87[b]	1.01[ab]	0.98[ab]	1.01[ab]	0.93[b]	0.06	0.82	0.41	0.66	0.70
d 9 to 23													
ADG, lb	0.73[ab]	0.68[a]	0.64[a]	0.72[ab]	0.69[ab]	0.75[ab]	0.71[ab]	0.79[b]	0.05	0.04	0.59	0.21	0.48
ADFI, lb	1.06	1.02	0.99	1.10	1.02	1.08	1.07	1.10	0.05	0.17	0.21	0.53	0.52
F/G	1.46[ab]	1.51[ab]	1.54[a]	1.54[a]	1.48[ab]	1.45[ab]	1.54[a]	1.40[b]	0.06	0.10	0.26	0.17	0.01
d 23 to 44													
ADG, lb	1.16[ab]	1.16[ab]	1.11[a]	1.15[ab]	1.19[b]	1.13[ab]	1.13[ab]	1.19[b]	0.03	0.93	0.43	0.01	0.07
ADFI, lb	1.91[a]	1.84[ab]	1.76[b]	1.79[ab]	1.78[b]	1.79[ab]	1.82[ab]	1.80[ab]	0.05	0.45	0.48	0.80	0.65
F/G	1.66[a]	1.59[b]	1.58[b]	1.56[bc]	1.49[d]	1.59[b]	1.61[ab]	1.51[cd]	0.02	0.19	0.95	0.001	0.001

continued

Table 4. The effects of AV-E Digest and XFE Liquid Energy on nursery pig performance[1]

	Treatment												
	1	2	3	4	5	6	7	8					
d 0 to 9:	Control	7.1% PEP2+	7.1% PEP2+, 3.75% SDAP[2]	7.1% PEP2+, 3.75% SDAP, 3% liquid energy	7.1% PEP2+, 3.75% SDAP 3% CWG[3]	12.5% AV-E[4], 2.5% SDBC[5]	12.5% AV-E, 2.5% SDBC, 3% liquid energy	12.5% AV-E, 2.5% SDBC, 3% CWG					
d 9 to 23:	Control	Control	3.8% PEP2+	3.8% PEP2+, 3% liquid energy	3.8% PEP2+, 3% CWG	7.5% AV-E	7.5% AV-E, 3% liquid energy	7.5% AV-E, 3% CWG		Probability, *P*<			
Item d 23 to 44:	Control	Control	Control	3% liquid energy	3% CWG	2.5% AV-E	2.5% AV-E +3% liquid energy	2.5% AV-E +3% CWG	SEM	AV-E[6]	Liquid energy[7]	CWG[8]	Liquid energy vs. CWG[9]
d 0 to 44													
ADG, lb	0.83^{ab}	0.82^{ab}	0.78^{a}	0.84^{ab}	0.84^{ab}	0.83^{ab}	0.82^{ab}	0.88^{b}	0.03	0.26	0.27	0.02	0.19
ADFI, lb	1.30^{a}	1.25^{ab}	1.20^{b}	1.26^{ab}	1.22^{ab}	1.25^{ab}	1.27^{ab}	1.26^{ab}	0.04	0.28	0.30	0.63	0.57
F/G	1.57^{a}	1.54^{ab}	1.53^{ac}	1.50^{bcd}	1.45^{de}	1.51^{bc}	1.54^{ab}	1.44^{e}	0.03	0.91	0.98	0.001	0.001
BW, lb													
d 0	11.0	11.0	11.0	11.0	11.0	10.9	10.9	10.9	0.1	0.33	0.80	0.55	0.72
d 44	47.5^{ab}	46.9^{ab}	45.6^{a}	48.1^{ab}	48.1^{ab}	47.5^{ab}	47.1^{ab}	49.7^{b}	1.6	0.31	0.29	0.02	0.21

a, b, c, d, e Means within the same row with different superscripts differ ($P < 0.05$).

[1] A total of 347 pigs (initially 11.0 lb) were used with 5 pigs per pen and 9 pens per treatment.

[2] SDAP: spray-dried animal plasma (AP 920, APC, Inc., Ames, IA).

[3] CWG: choice white grease.

[4] AV-E: AV-E Digest (XFE Products, Des Moines, IA.).

[5] SDBC: spray-dried blood cells (AP302G, APC, Inc., Ames, IA).

[6] AV-E = Treatments 3, 4, and 5 vs. 6, 7, and 8.

[7] Liquid energy (XFE Products, Des Moines, IA.); Treatments 3 and 6 vs. 4 and 7.

[8] CWG = Treatments 3 and 6 vs. 5 and 8.

[9] Liquid energy vs. CWG = Treatments 4 and 7 vs. 5 and 8.

Effects of Ingredients of Plant and Animal Origin on Nursery Pig Performance

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Summary

A total of 224 weanling pigs were used in a 34-d growth assay. The pigs were sorted by gender and ancestry, blocked by BW, and assigned to pens (7 pigs/pen and 8 pens/treatment) in a randomized complete block design. From d 0 to 10, treatments were arranged as a 2 × 2 factorial with main effects of primary protein sources (plant vs. animal) and inclusion of soybean meal (none vs. 30%). The plant products diets had wheat gluten and corn gluten, and the animal products diets had animal plasma and fish meal as primary protein sources. All diets were formulated to be at least 120, 120, and 110% of the requirements for all essential amino acids, vitamins, and minerals, respectively, as suggested in NRC guidelines. Soybean meal replaced corn in the diet to create the diets containing soybean meal. From d 10 to 34, all pigs were fed the same corn-soybean meal–based diets to allow determination of any carryover effects (or disappearance thereof) for the diets fed for the first 10 d immediately after weaning.

No interactions were observed for d 0 to 10, 10 to 34, or 0 to 34 ($P > 0.12$) among primary protein source and inclusion of soybean meal for ADG, ADFI, or F/G. The use of animal products increased ($P < 0.02$) ADG by 61% for d 0 to 10 and 7% for d 0 to 34, respectively. Soybean meal increased ($P < 0.001$) ADG by 31% for d 0 to 10 and tended to improve overall ADG ($P < 0.07$) by 5%; thus, we conclude that use of animal products (plasma protein and fish meal) and inclusion of soybean meal (30% of the diet) enhanced growth performance in weanling pigs.

Key words: animal protein sources, nursery pig, soybean meal

Introduction

The cost of pork production is at an all-time high, and feed represents 60 to 70% of that cost. Diets for weanling pigs routinely are rich in specialty products (e.g., plasma protein, fish meal, and whey powder) that are quite expensive; furthermore, interest is growing in some places (such as Europe) in feeding vegetable-based diets to avoid the possibility of transmitting feedborne illness from animal co-products to livestock and poultry. These concerns lend themselves to the exclusive use of plant protein sources in diets for weanling pigs even if some growth performance might be sacrificed. We designed an experiment to determine the effects of diets with and without animal-derived feed ingredients and high inclusion of soybean meal on growth performance in weanling pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

For this experiment, 224 weanling pigs were used in a 34-d growth assay. The pigs were sorted by gender and ancestry and blocked by BW with 7 pigs per pen and 8 pens per treatment. Treatments were arranged as a 2 × 2 factorial with main effects of protein sources (plant vs. animal) and inclusion of soybean meal (none vs. 30%). Pigs were assigned to 5-ft × 5-ft pens equipped with one water nipple and one four-hole dry feeder. Experimental diets were fed from d 0 to 10 and common diets thereafter for d 10 to 23 and d 23 to 34 with all feed and water consumed on an ad libitum basis.

The diets were formulated to be at least 120, 120, and 110% of the requirements for all essential amino acids, vitamins, and minerals, respectively, as suggested in NRC guidelines (Table 1). Soybean meal (30%) replaced corn to form the diets containing soybean meal. Spray-dried animal plasma and fish meal replaced corn gluten and a portion of the wheat gluten to form the diets containing animal proteins. The diets for d 0 to 10 were fed as pellets, and the diets for d 10 to 23 and d 23 to 34 were fed in meal form. Pigs and feeders were weighed on d 0, 10, 23, and 34 with ADG, ADFI, and F/G used as response criteria. The PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) was used for all data analyses in this randomized complete design. Orthogonal contrasts (plant vs. animal protein sources, none vs. 30% soybean meal, and the interaction effect) were used to separate treatment means.

Results and Discussion

No interactions for d 0 to 10, 10 to 34, or 0 to 34 ($P > 0.12$) were observed among primary protein source and inclusion of soybean meal for ADG, ADFI, or F/G (Table 2). The use of animal products increased ($P < 0.02$) ADG by 61% for d 0 to 10 and 7% for d 0 to 34, respectively. Soybean meal increased ($P < 0.001$) ADG by 31% for d 0 to 10 and tended to improve ADG overall ($P < 0.07$) by 5%. Thus, we conclude that use of animal products (plasma protein and fish meal) and inclusion of soybean meal (30% of the diet) enhanced growth performance in weanling pigs.

Table 1. Composition of experimental diets (as-fed basis)

	d 0 to 10					
Protein source:	Plant		Animal			
Ingredient, % soybean meal:	None	30%	None	30%	d 10 to 23	d 23 to 34
Corn	30.79	0.79	33.03	3.03	43.68	59.51
Soybean meal (48.5%)	---	30.00	---	30.00	22.45	30.10
Dried whey	30.00	30.00	30.00	30.00	20.00	--
Soybean oil	4.00	4.00	4.00	4.00	2.00	5.00
Spray-dried plasma	---	---	10.00	10.00	3.00	---
Fish meal	---	---	10.00	10.00	5.00	---
Wheat gluten	15.00	15.00	10.00	10.00	---	---
Corn gluten	13.00	13.00	---	---	---	
L-lysine·HCl	1.38	1.38	0.17	0.17	0.31	0.47
L-threonine	0.27	0.27	---	---	0.13	0.20
DL-methionine	0.08	0.08	0.02	0.02	0.20	0.19
L-tryptophan	0.09	0.09	---	---	0.03	0.03
L-valine	0.10	0.10	---	---	0.08	0.09
Monocalcium phosphate	1.79	1.79	---	---	0.79	1.80
Limestone	1.30	1.30	0.59	0.59	0.68	1.04
Salt	0.20	0.20	0.20	0.20	0.30	0.38
Vitamins	0.26	0.26	0.25	0.25	0.25	0.25
Minerals	0.65	0.65	0.65	0.65	0.15	0.15
Antibiotic[1]	0.70	0.70	0.70	0.70	0.70	0.70
Zinc oxide[b]	0.39	0.39	0.39	0.39	0.25	---
Copper sulfate[2]	---	---	---	---	---	0.09
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis, %						
CP, %	27.60	39.40	28.50	40.30	22.80	20.00
SID lysine[3]	1.68	2.43	1.63	2.39	1.52	1.31
Ca	1.03	1.12	0.99	1.09	0.88	0.80
Total P	0.77	0.89	0.80	0.93	0.79	0.75

[1] To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.
[2] To supply 3,000 ppm Zn for d 0 to 10, 2,000 ppm Zn for d 10 to 23, and 20 ppm Cu for d 23 to 34.
[3] Standardized ileal digestible (SID) lysine.

Table 2. Effects of specialty ingredient sources and soybean meal concentration on nursery pig performance[1]

Protein source:	Plant		Animal			Probability, *P*<[2]		
Item Soybean meal:	None	30%	None	30%	SE	1	2	3
d 0 to 10								
ADG, lb	0.24	0.38	0.46	0.54	0.03	0.001	0.002	0.36
ADFI, lb	0.32	0.36	0.48	0.49	0.02	0.001	0.28	0.52
F/G	1.39	0.95	0.91	0.89	0.38	0.20	0.148	0.27
d 10 to 34								
ADG, lb	1.36	1.35	1.34	1.41	0.04	0.50	0.40	0.27
ADFI, lb	1.69	1.77	1.74	1.78	0.04	0.41	0.11	0.49
F/G	1.24	1.31	1.30	1.26	0.03	0.98	0.712	0.12
d 0 to 34								
ADG, lb	1.04	1.08	1.10	1.17	0.03	0.02	0.07	0.49
ADFI, lb	1.30	1.37	1.38	1.41	0.03	0.04	0.10	0.46
F/G	1.24	1.27	1.26	1.20	0.03	0.40	0.69	0.15

[1] A total of 227 pigs, initial average weight of 14.2 lb and 21 d of age were used, with 7 pigs per pen and 8 replications per treatment.
[2] Contrasts were (1) plant vs. animal, (2) without vs. with soybean meal, and (3) plant vs. animal × without vs. with soybean meal.

Effects of Increasing Dietary Wheat Middlings on Nursery Pig Performance from 15 to 50 lb

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Summary

A total of 210 pigs (PIC 327 × 1050, initially 15.12 lb BW) were used in a 35-d trial to evaluate the effects of increasing dietary wheat middlings (midds) on growth performance of 15- to 50-lb nursery pigs. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 6 replications per treatment. The 5 corn-soybean meal–based diets contained 0, 5, 10, 15, or 20% midds. Pigs were fed in a 2-phase feeding program from d 0 to 14 and d 14 to 35. Diets were not balanced for energy; thus, as midds increased, dietary energy concentrations decreased.

From d 0 to 14, midds had no effect on growth performance; however, from d 14 to 35, pigs fed increasing midds had decreased ADG (linear, $P < 0.02$) and poorer F/G (linear, $P < 0 .004$). Furthermore, pigs fed increasing midds had lower (linear, $P < 0.05$) feed cost/pig, revenue/pig, and income over feed cost (IOFC), and a tendency for increased (quadratic, $P < 0.07$) feed cost/lb gain. Overall (d 0 to 35), increasing dietary midds worsened F/G (quadratic, $P < 0.01$), driven by poorer F/G for pigs fed 15 and 20% midds. We also observed a quadratic effect ($P < 0.004$) for feed cost/lb gain, with inclusion rates of 0 and 20% having the highest value. Caloric efficiency responded in a quadratic manner ($P < 0.01$) on both an ME and NE basis with improved caloric efficiencies at intermediate levels (mainly 5%) of dietary middlings compared with 0 and 20% inclusions.

These data suggest that the inclusion of midds at levels up to 15% do not negatively affect performance in 15- to 50-lb nursery pigs. Although we observed a linear decrease in overall IOFC, both inclusion rates of 5 and 10% were numerically more profitable than the control.

Key words: growth, nursery pig, wheat middlings

Introduction

Wheat middlings are a wheat milling by-product that consist of fine particles of wheat bran, wheat shorts, wheat germ, and wheat flour; midds contain no more than 9.5% crude fiber (CF). With the sudden increase in the price of corn and soybean meal, wheat midds have become a more common ingredient in swine diets. Wheat midds have higher CP and CF but lower dietary energy than corn (corn ME = 1,551 kcal/lb; wheat middlings ME = 1,372 kcal/lb; NRC, 1998[2]), which must be accounted for when used in swine diets.

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[1] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[2] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

Although extensive research has been conducted with midds and their effects on growing and finishing pigs[3], little data is available on its effects in corn-soybean meal–based early nursery diets. In a recent study with nursery pigs fed midds from 25 to 50 lb BW, midds had no effect on performance when included up to 15% of the diet. Thus, although the effects in mid-to-late nursery phases have been quantified, research needs to be completed with younger nursery pigs to determine if a similar response exists throughout all nursery phases.

The objective of this study was to determine the effects of increasing dietary wheat midds (0, 5, 10, 15, and 20%) on growth performance, caloric efficiency, and economics of nursery pigs from 15 to 50 lb.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 210 pigs (PIC 327 × 1050, initially 15.12 lb BW and 26 d of age) were used in a 35-d growth trial to determine the effects of dietary midds on pig growth performance, caloric efficiency, and economics. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a completely randomized design with 7 pigs per pen and 6 replications per treatment. The 5 treatment diets included 0, 5, 10, 15, or 20% midds (Tables 1 and 2). Diets were not balanced for energy, so as the level of midds increased, dietary ME decreased. The ME value for midds used in diet formulation was 1,372 kcal/lb (NRC, 1998), and the NE value was 1,850 (INRA, 2004[4]). All diets were formulated to a constant standardized ileal digestible lysine level to ensure changes in performance were due to dietary energy differences rather than differences in amino acid concentrations. Diets were fed in two phases, with Phase 1 from d 0 to 14 and Phase 2 from d 14 to 35. All diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill.

Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig. Pig weight and feed disappearance were measured on d 0, 7, 14, 21, 28, and 35 of the trial to determine ADG, ADFI, and F/G.

Wheat midds and complete diet samples were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, CF, Ca, P, crude fat, and ash (Tables 3 and 4). Bulk density and particle size of the midds and complete diets were also measured. Caloric efficiencies of pens was determined on an ME and NE (INRA, 2004[5]) basis. Efficiencies were calculated by multiplying total intake by the energy level in the feed (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed

[3] Barnes et al., Swine Day 2010, Report of Progress 1038, pp. 104–114.
[4] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.
[5] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

cost/lb gain, revenue/pig, and IOFC were also calculated. Diet costs were determined with the following ingredient costs: corn = \$0.14/lb; soybean meal = 0.24/lb; midds = 0.12/lb; DDGS = 0.14/lb. Feed cost/pig was determined by total feed intake × cost/lb feed. Feed cost/lb gain was calculated using F/G × feed cost/lb. Revenue/pig was determined by total gain × \$0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Contrasts were used to compare linear and quadratic effects of increasing wheat midds. Statistics were considered significant at $P < 0.05$ and tendencies at $P > 0.05$ but < 0.10.

Results and Discussion

The chemical analysis of the midds (Table 3) revealed that CP, CF, Ca, and P were all slightly higher than the formulated values, whereas the fat content was slightly lower than formulated values. The analysis of the dietary treatments showed that fiber analysis of ADF, NDF, and CF increased as expected as dietary wheat midds increased in the diet (Table 4). Diet bulk density also decreased as midds inclusion levels increased as expected, but they decreased slightly for Phase 2 compared with Phase 1 diets in this experiment.

From d 0 to 14, midds level had no effect on growth performance (Table 5); however, from d 14 to 35, pigs fed increasing midds had decreased (linear, $P < 0.02$) ADG and worse (linear, $P < 0 .004$) F/G. Subsequently, pigs fed increasing midds had lower (linear, $P < 0.05$) feed cost/pig, revenue/pig, and IOFC but a tendency for increased (quadratic, $P < 0.07$) feed cost/lb gain (Table 6).

Overall, (d 0 to 35), as dietary midds increased, F/G became poorer (quadratic, $P < 0.01$). This effect was mainly attributed to a notable increase for pigs fed 20% midds. For caloric efficiency, the response was quadratic ($P < 0.01$) on an ME and NE basis as the level of midds increased in the diet. The quadratic response is supported by the worst caloric efficiencies observed for both ME and NE at 0 and 20% inclusion rates. A quadratic effect ($P < 0.004$) also occurred for feed cost/lb gain, with inclusion rates of 0 and 20% having the highest value. Notably, the highest numerical IOFC occurred at 5 and 10% midds inclusion rates.

These data support other recent data in that midds inclusion levels up to 15% do not affect nursery pig performance, even when not formulated to a constant energy level. More research is needed to further explain the lack of negative effect when feeding up to 15% midds in nursery diets. These data support the potential use of midds in diets for 15- to 50-lb nursery pigs to improve net returns.

Table 1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1					Phase 2				
Item Wheat middlings, %:	0	5	10	15	20	0	5	10	15	20
Ingredient, %										
Corn	54.77	51.01	47.25	43.49	39.73	63.74	59.97	56.22	52.45	48.71
Soybean meal (46.5% CP)	29.32	28.09	26.86	25.63	24.40	32.79	31.56	30.33	29.10	27.87
Wheat middlings	---	5.00	10.00	15.00	20.00	---	5.00	10.00	15.00	20.00
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	---	---	---	---	---
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	---	---	---	---	---
Monocalcium phosphate (21% P)	0.650	0.575	0.500	0.425	0.350	1.050	1.000	0.900	0.825	0.750
Limestone	0.875	0.913	0.950	0.988	1.025	0.950	0.975	1.025	1.075	1.100
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.25	0.27	0.29	0.31	0.33	0.33	0.35	0.37	0.39	0.41
DL-methionine	0.130	0.130	0.130	0.130	0.130	0.135	0.135	0.135	0.135	0.135
L-threonine	0.125	0.138	0.140	0.148	0.155	0.125	0.135	0.140	0.145	0.155
Phytase[2]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100	100	100	100	100	100	100	100	100	100

[1]Phase 1 diets were fed from d 0 to 14, and Phase 2 diets were fed from d 14 to 35.
[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

Table 2. Phase 1 and 2 calculated nutrient profile (as-fed basis)[1]

	Phase 1					Phase 2				
Item Wheat middlings, %:	0	5	10	15	20	0	5	10	15	20
Calculate analysis										
Standard ileal digestible (SID) amino acids, %										
Lysine	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	62	62	61	60	60	61	61	60	59	59
Leucine:lysine	127	125	123	121	119	129	127	125	123	121
Methionine:lysine	34	34	34	34	34	34	34	33	33	33
Met & Cys:lysine	58	58	58	58	58	58	58	58	58	58
Threonine:lysine	65	65	65	65	65	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	68	68	67	68	68	67	67	67
Total lysine, %	1.46	1.46	1.45	1.45	1.45	1.42	1.41	1.41	1.41	1.40
ME, kcal/lb	1,500	1,492	1,484	1,476	1,468	1,504	1,495	1,487	1,479	1,471
NE Nobet, kcal/lb	1,091	1,077	1,063	1,049	1,035	1,073	1,059	1,045	1,031	1,017
SID lysine:ME, g/Mcal	3.99	4.01	4.04	4.06	4.08	3.86	3.88	3.90	3.93	3.95
CP, %	21.8	21.7	21.6	21.6	21.5	21.2	21.1	21.0	20.9	20.9
Crude fiber, %	2.3	2.6	2.8	3.0	3.2	2.7	2.9	3.1	3.3	3.6
NDF, %	3.6	4.2	4.8	5.4	5.9	4.1	4.7	5.3	5.9	6.5
ADF, %	1.4	1.6	1.7	1.9	2.1	1.6	1.8	1.9	2.1	2.3
Ca, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %	0.66	0.67	0.68	0.69	0.70	0.63	0.64	0.65	0.66	0.67
Available P, %	0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42

[1]Phase 1 diets were fed from d 0 to 14, and Phase 2 diets were fed from d 14 to 35.

Table 3. Chemical analysis of wheat middlings (as-fed basis)[1]

Item	Percentage
DM, %	91.37
CP, %	16.10 (15.90)
ADF, %	11.00
NDF, %	33.70
Crude fiber, %	8.50 (7.00)
NFE, %	57.00
Ca, %	0.15 (0.12)
P, %	1.12 (0.93)
Fat, %	3.90 (4.20)
Ash, %	5.50
Particle size, µ	532
Bulk density, lb/bu	22.26

[1] Values in parentheses indicate those used in diet formulation.

Table 4. Chemical analysis of diets containing wheat middlings (as-fed basis)[1]

	Phase I					Phase II				
Item Wheat middlings, %:	0	5	10	15	20	0	5	10	15	20
DM, %	89.51	89.82	90.49	89.83	90.60	88.73	88.62	89.01	88.66	89.45
CP, %	22.20	21.30	22.00	24.00	20.90	21.40	20.90	21.10	21.30	21.10
ADF, %	3.10	3.20	4.10	4.70	4.10	3.30	4.10	5.00	5.10	5.60
NDF, %	6.70	8.00	9.10	11.40	11.20	7.60	9.10	14.10	11.90	14.00
Crude fiber, %	1.80	2.20	2.60	3.00	2.90	2.40	2.70	3.40	3.30	3.70
NFE, %	57.20	57.70	57.10	53.90	58.10	57.50	57.80	56.00	55.40	56.50
Ca, %	1.12	1.17	1.18	1.10	1.11	0.77	0.81	0.92	1.17	0.79
P, %	0.67	0.63	0.73	0.71	0.71	0.62	0.63	0.71	0.74	0.72
Fat, %	2.30	2.20	2.40	2.50	2.50	2.60	2.50	2.80	2.50	2.90
Ash, %	5.93	6.35	6.31	6.39	6.26	4.78	4.79	5.66	6.17	5.20
Bulk density lb/bu	62.59	59.48	55.74	52.15	50.24	58.03	54.12	49.77	48.79	46.66

[1] A composite sample consisting of 6 subsamples was used for analysis.

Table 5. The effects of increasing wheat middlings on nursery pig growth performance[1]

	Wheat middlings, %						Probability, *P*<	
Item	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 14								
ADG, lb	0.45	0.46	0.47	0.44	0.46	0.03	0.99	0.89
ADFI, lb	0.72	0.69	0.70	0.70	0.74	0.03	0.76	0.30
F/G	1.61	1.50	1.53	1.61	1.60	0.06	0.69	0.25
d 14 to 35								
ADG, lb	1.29	1.29	1.27	1.26	1.20	0.03	0.02	0.26
ADFI, lb	1.93	1.90	1.94	1.90	1.90	0.04	0.55	0.93
F/G	1.50	1.47	1.52	1.51	1.58	0.02	0.004	0.07
d 0 to 35								
ADG, lb	0.95	0.96	0.95	0.93	0.90	0.03	0.11	0.39
ADFI, lb	1.45	1.42	1.44	1.42	1.43	0.04	0.69	0.81
F/G	1.52	1.48	1.52	1.53	1.58	0.02	0.004	0.01
ME/G, kcal/lb	2,286	2,207	2,256	2,258	2,330	25.5	0.10	0.01
NE/G, kcal/lb	1,637	1,569	1,591	1,580	1,617	17.9	0.61	0.01
BW, lb								
d 0	15.13	15.13	15.11	15.10	15.11	0.13	0.88	0.93
d 14	21.45	21.61	21.69	21.28	21.57	0.48	0.93	0.90
d 35	48.52	48.70	48.43	47.64	46.91	0.90	0.15	0.49

[1] A total of 210 pigs (PIC 327 × 1050, initially 25.2 lb BW and 26 d of age) were used in a 35-d growth trial with 7 pigs per pen and 6 pens per treatment.

Table 6. Economics of increasing wheat middlings in nursery pig diets[1]

	Wheat middlings, %						Probability, *P*<	
Item	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 14								
Feed cost/pig, $	2.51	2.38	2.38	2.38	2.48	0.117	0.85	0.30
Feed cost/lb gain, $[2]	0.40	0.37	0.37	0.39	0.39	0.014	0.86	0.24
Total revenue/pig, $[3,4]	4.11	4.21	4.27	4.02	4.20	0.299	0.99	0.88
IOFC[5]	1.60	1.83	1.89	1.64	1.72	0.197	0.93	0.40
d 14 to 35								
Feed cost/pig,$	5.10	4.97	5.02	4.86	4.81	0.107	0.05	0.93
Feed cost/lb gain, $	0.19	0.18	0.19	0.18	0.19	0.002	0.19	0.07
Total revenue/pig, $	17.59	17.61	17.39	17.14	16.47	0.363	0.03	0.32
IOFC	12.49	12.64	12.37	12.28	11.66	0.285	0.03	0.22
d 0 to 35								
Feed cost/pig,$	7.62	7.35	7.40	7.24	7.29	0.205	0.25	0.58
Feed cost/lb gain, $	0.23	0.22	0.22	0.22	0.23	0.003	0.56	0.004
Total revenue/pig, $	21.70	21.82	21.66	21.16	20.67	0.578	0.15	0.48
IOFC	14.09	14.47	14.26	13.92	13.38	0.409	0.14	0.21

[1] A total of 210 pigs (PIC 327 × 1050, initially 25.2 lb BW and 26 d of age) were used in a 35-d growth trial with 7 pigs per pen and 6 pens per treatment.

[2] Feed cost/lb gain = feed cost/lb × F/G, assuming grinding = $5/ton, mixing = $3/ton, and delivery and handling = $7/ton.

[3] One pound of carcass gain was considered to be worth $0.65.

[4] Total revenue/pig = total gain/pig × $0.65.

[5] Income over feed cost = total revenue/pig – feed cost/pig.

Effects of Increasing Dietary Wheat Middlings and Dried Distillers Grains with Solubles on Nursery Pig Growth Performance

J. A. De Jong, J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz[1]*, and J. L. Nelssen*

Summary

A total of 180 pigs (PIC 327 × 1050, initially 26.9 lb BW) were used in a 21-d trial to evaluate the effects of increasing dietary wheat middlings (midds) and dried distillers grains with solubles (DDGS) on nursery pig growth performance. Pens of pigs were balanced by initial BW and were randomly allotted to 1 of 6 dietary treatments with 5 replications per treatment. The 6 corn-soybean meal–based diets were arranged in a 2 × 3 factorial with main effects of DDGS (0 or 20%) and wheat midds (0, 10, or 20%). Diets were not balanced for energy, so as wheat midds increased, dietary energy concentration decreased.

Overall (d 0 to 21), no DDGS × wheat midds interactions ($P > 0.12$) were observed. Pigs fed increasing wheat midds had decreased (linear, $P < 0.02$) ADG and poorer (linear, $P < 0.01$) F/G. Feed cost/pig and revenue/pig both decreased (linear, $P < 0.02$) with increasing wheat midds. Feeding pigs a diet containing 20% DDGS did not affect growth performance ($P > 0.59$) but decreased ($P < 0.005$) feed cost/pig. These data suggest that adding DDGS to diets containing wheat midds can be used to decrease feed costs when formulating nursery pig diets; however, increasing wheat midds decreased growth rate and economic return in this experiment.

Key words: DDGS, nursery pig, wheat middlings

Introduction

Wheat middlings and corn DDGS are common high-fiber (wheat midds = <9.5%; DDGS = 7.3%) by-products of the wheat milling and ethanol industries, respectively. With corn increasing in price, these two ingredients have become common alternatives to help lower feed costs. Although traditional DDGS have an energy value similar to corn, midds have a lower energy concentration (ME = 1,372 kcal/lb; NRC, 1998[2]).

In a recent trial, nursery pigs fed over 15% midds had decreased ADG and ADFI but relatively unchanged F/G (De Jong et al., 2011[3]). In addition, research has shown that DDGS can be fed in nursery diets without altering performance. Although research has been conducted that combines dietary midds and DDGS in diets for growing and finishing pigs, no data are available on their potential interactive effects in nursery diets. The objective of this study was to determine the effects of increasing dietary wheat

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[2] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[3] De Jong et al., Swine Day 2011, Report of Progress 1056, pp. 114–117.

midds (10 and 20%) in combination with DDGS (20%) on growth performance of nursery pigs from 25 to 50 lb.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 180 pigs (PIC 327 × 1050, initially 26.9 lb BW and 39 d of age) were used in a 21-d growth trial. Pigs were allotted to pens by initial BW so pen initial average BW was similar among pens; pens were then assigned to treatments in a completely randomized design with 6 pigs per pen and 5 replications per treatment. All pigs were fed a common diet before being allotted to treatments. The 6 treatment diets were arranged in a 2 × 3 factorial with main effects of wheat midds (0, 10, and 20%) with or without 20% DDGS (Table 1). For diet formulation, the ME value of DDGS was similar to that of corn (1,551 kcal/kg), and the ME value of wheat midds was 1,372 kcal/lb (NRC, 1998). Diets were not balanced for energy; thus, increasing wheat midds decreased ME. All diets were formulated to a constant standardized ileal digestible (SID) lysine level to ensure changes in performance were due to dietary energy differences rather than differences in amino acid concentrations. All diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill.

Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig. Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G.

Samples of wheat midds, DDGS, and complete diets were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, crude fiber, fat, ash, Ca, and P (Tables 2 and 3). In addition, bulk density and particle size of the wheat midds, DDGS, and complete diets was determined. Caloric efficiency was determined on both an ME and NE basis using NE values obtained from INRA (2004[4]). Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed cost/lb gain, revenue/pig, and income over feed cost (IOFC) were also calculated. Diet costs were determined with the following ingredient prices: corn, $8.00/bu; soybean meal, $480/ton; midds, $240/ton; DDGS, $280/ton. Feed cost/pig was determined by total feed intake × cost/lb feed. Feed cost/lb gain was calculated using F/G × feed cost/lb. Revenue/pig was determined by total gain × $0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit. Initial weight was used as a covariate for all statistical analysis. Data were analyzed for wheat midds × DDGS interactions as well as wheat midds and DDGS main effects.

[4] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Polynomial contrasts were used to determine linear and quadratic effects of increasing wheat midds. Statistics were considered significant at $P < 0.05$ and were considered tendencies at $P > 0.05$ but < 0.10.

Results and Discussion

The chemical analysis of the wheat midds and DDGS (Table 2) revealed that most nutrients were similar to formulated values. Crude protein levels were slightly higher for both ingredients than formulated values. Crude fiber levels were lower for midds but slightly higher for DDGS than calculated values, and the P levels were slightly higher than the formulated values for both ingredients. As expected, analysis of the dietary treatments showed increased fiber component levels with the addition of increasing wheat midds or DDGS to the diet. Diet bulk density decreased with increasing wheat midds as well as when DDGS were added to the diet.

Overall (d 0 to 21), no wheat midds × DDGS interactions ($P > 0.12$) were observed for any growth performance or economic measurements (Table 4). Increasing wheat midds decreased (linear, $P < 0.02$) ADG and final BW. Increasing wheat midds resulted in poorer (linear; $P < 0.01$) F/G with no change in ADFI. Feed cost/pig and total revenue/pig also decreased (linear, $P < 0.02$) with increasing wheat midds. No differences in growth performance criteria were observed when 20% DDGS was fed ($P > 0.59$), but adding DDGS to the diet decreased ($P < 0.005$) feed cost/pig. When feed efficiency was evaluated on an ME or NE kcal per unit of gain basis no differences were observed in energetic efficiency.

The poorer feed efficiency of pigs as more wheat midds were added was not completely unexpected, because diets were not balanced for energy. Pigs did not compensate by consuming more feed, so ADG was reduced. In the current trial, this effect occurred when 10% midds were included, in contrast to our previous study, when it did not occur until 15% midds was fed (De Jong et al., 2011[3]).

An important finding of the research was that no interactive effects occurred when feeding 20% DDGS in combination with up to 20% midds for nursery pigs; thus, these two ingredients can be used together without interactive effects to help reduce feed costs.

Table 1. Diet composition (as-fed basis)[1]

	DDGS, %:[2]	0			20		
Item	Wheat middlings, %:	0	10	20	0	10	20
Ingredient, %							
Corn		63.74	56.22	48.71	47.57	40.05	32.54
Soybean meal (46.5% CP)		32.79	30.33	27.87	29.27	26.81	24.34
DDGS		---	---	---	20.00	20.00	20.00
Wheat middlings		---	10.00	20.00	---	10.00	20.00
Monocalcium phosphate (21% P)		1.05	0.90	0.75	0.60	0.45	0.30
Limestone		0.95	1.03	1.10	1.20	1.28	1.35
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix		0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl		0.33	0.37	0.41	0.37	0.41	0.45
DL-methionine		0.135	0.135	0.135	0.045	0.045	0.045
L-threonine		0.125	0.140	0.155	0.070	0.085	0.100
Phytase[3]		0.125	0.125	0.125	0.125	0.125	0.125
Total		100	100	100	100	100	100
Calculated analysis							
Standard ileal digestible (SID) amino acids, %							
Lysine		1.28	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine		61	60	59	65	64	62
Leucine:lysine		129	125	121	150	146	142
Methionine:lysine		34	33	33	30	30	30
Met & Cys:lysine		58	58	58	58	58	58
Threonine:lysine		63	63	63	63	63	63
Tryptophan:lysine		17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine		68	67	67	74	73	73
Total lysine, %		1.42	1.41	1.40	1.45	1.45	1.44
ME, kcal/lb[4]		1,504	1,487	1,471	1,507	1,490	1,474
NE, kcal/lb[5]		1,073	1,045	1,017	1,085	1,057	1,029
SID lysine:ME, g/Mcal		3.86	3.90	3.95	3.85	3.90	3.94
CP, %		21.2	21.0	20.9	23.5	23.4	23.2
CF, %		2.7	3.1	3.6	2.2	2.6	3.1
NDF, %		4.1	5.3	6.5	6.4	7.6	8.8
ADF, %		1.6	1.9	2.3	2.8	3.1	3.5
Ca, %		0.69	0.69	0.69	0.69	0.69	0.69
P, %		0.63	0.65	0.67	0.60	0.63	0.65
Available P, %		0.30	0.30	0.30	0.30	0.30	0.30

[1]Treatment diets fed for 21 d.
[2] Dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.
[4] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[5] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Table 2. Chemical analysis of wheat middlings and dried distillers grains with solubles (DDGS; as-fed basis)[1]

Item	Wheat middlings	DDGS
DM, %	90.45	92.16
CP, %	16.50 (15.90)	29.50 (27.20)
ADF, %	10.30	10.20
NDF, %	32.40	29.50
Crude fiber, %	8.30 (7.00)	7.10 (7.30)
Ca, %	0.10 (0.12)	0.07 (0.03)
P, %	1.07 (0.93)	0.88 (0.71)
Fat, %	4.50	9.50
Ash, %	5.14	4.81
Bulk density lb/bu	22.99	37.49

[1] Values in parentheses indicate those used in diet formulation; values in parentheses from NRC, 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

Table 3. Chemical analysis of diets containing wheat middlings and dried distillers grains with solubles (DDGS; as-fed basis)[1]

DDGS, %:	0			20		
Item Midds, %:	0	10	20	0	10	20
DM, %	91.08	90.94	91.19	91.55	91.83	91.81
CP, %	22.30	21.60	21.20	23.90	23.80	22.30
ADF, %	2.30	3.10	3.70	4.40	5.50	5.50
NDF, %	9.20	12.10	14.90	11.40	14.60	14.70
Crude fiber, %	2.40	2.90	3.30	3.10	3.80	4.30
Ca, %	0.85	0.91	0.83	0.80	0.87	0.73
P, %	0.63	0.66	0.68	0.62	0.68	0.68
Fat, %	2.60	2.90	3.00	3.90	4.20	4.30
Ash, %	5.11	5.44	5.46	5.18	5.58	5.18
Bulk density, lb/bu	53.38	48.70	46.39	48.75	44.93	42.37

[1] A composite sample consisting of 6 subsamples was used for analysis.

Table 4. The effects of wheat middlings and dried distillers grains with solubles (DDGS) on nursery pig growth performance[1]

DDGS, %:	0			20				Probability, $P<$	
Item Midds, %:	0	10	20	0	10	20	SEM[2,3]	Linear	Quadratic
d 0 to 21									
ADG, lb	1.31	1.24	1.23	1.28	1.28	1.23	0.029	0.02	0.98
ADFI, lb	2.09	2.04	2.04	2.04	2.10	2.10	0.036	0.56	0.78
F/G	1.59	1.64	1.66	1.60	1.65	1.71	0.032	0.01	0.82
Caloric efficiency[4]									
ME	2,397	2,440	2,442	2,406	2,453	2,519	46.76	0.15	0.81
NE	1,710	1,715	1,688	1,733	1,740	1,759	32.69	0.84	0.77
BW, lb									
d 0	26.7	26.8	26.7	26.7	26.7	27.7	0.636	0.59	0.79
d 21	54.25	53.0	52.6	53.6	53.6	53.6	0.595	0.02	0.98

[1] A total of 180 pigs (PIC 327 × 1050, initially 26.9 lb BW and 39 d of age) were used in a 21-d growth trial with 6 pigs per pen and 5 pens per treatment.
[2] No wheat midds × DDGS interactions were observed, $P > 0.12$.
[3] No DDGS effects, $P > 0.41$.
[4] Caloric efficiency is expressed as kcal/lb gain.

Table 5. Economics of wheat middlings and dried distillers grains with solubles (DDGS) in nursery pig diets[1]

DDGS, %:	0			20				Probability, $P<$	
Item Midds, %:	0	10	20	0	10	20	SEM[2,3]	Linear	Quadratic
d 0 to 21									
Feed cost/pig, $	8.38	7.95	7.88	7.89	7.87	7.39	0.141	0.001	0.86
Feed cost/lb gain, $[4]	0.30	0.30	0.30	0.29	0.29	0.29	0.006	0.88	0.84
Total revenue/pig, $[5,6]	17.94	17.09	17.18	17.51	17.46	16.46	0.387	0.02	0.98
IOFC[7]	9.56	9.14	9.30	9.61	9.60	9.07	0.302	0.18	0.96

[1] A total of 180 pigs (PIC 327 × 1050, initially 26.9 lb BW and 39 d of age) were used in a 21-d growth trial with 6 pigs per pen and 5 pens per treatment.
[2] No midds × DDGS interactions, $P > 0.12$.
[3] DDGS effects, $P < 0.005$ for feed cost/pig; no other significant DDGS effects.
[4] Feed cost/lb gain = feed cost/lb × F/G, assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton.
[5] One pound of live gain was considered to be worth $0.65.
[6] Total revenue/pig = total gain/pig × $0.65.
[7] Income over feed cost = total revenue/pig – feed cost/pig.

Effects of Increasing Wheat Middlings and Net Energy Formulation on Nursery Pig Growth Performance

J. A. De Jong, J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz[1], and J. L. Nelssen

Summary

A total of 210 pigs (PIC 327 × 1050, initially 15.15 lb) were used in a 29-d trial to evaluate the effects of dietary wheat middlings and NE formulation on nursery pig growth performance. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 6 replications per treatment. The 5 corn-soybean meal–based diets were: (1) corn-soybean meal (positive control), (2) 10% added midds, (3) 20% added midds, (4) Treatment 2 with 1.4% added soybean oil, and (5) Treatment 3 with 2.8% added soybean oil. Treatments 4 and 5 were balanced on an NE basis equal to that of the positive control. Feed ingredients were assigned NE values for the growing pig by INRA (2004[2]). Treatment diets were fed in a 2-phase feeding program from d 0 to 12 and 12 to 29.

From d 0 to 12, a midds × fat interaction was observed ($P < 0.01$) for ADFI. This was the result of pigs fed increasing midds having increased feed intake with no added fat but decreased intake when increasing fat was combined with increasing midds. From d 12 to 29, no midds × fat interactions were observed. For the main effects of midds (regardless of NE), there was a tendency for decreased ($P < 0.09$) ADG and poorer ($P < 0.001$) F/G. Feed efficiency was similar among pigs fed either 0 or 10% wheat midds, but decreased (quadratic, $P < 0.03$) when midds increased to 20% of the diet; however, balancing on a NE basis tended to increase ($P < 0.09$) ADG compared with not balancing for NE when midds were added.

Overall (d 0 to 29), no midds × fat interactions were observed. Pigs fed increasing midds exhibited a tendency toward poorer (linear, $P < 0.06$) F/G and energetic efficiency when expressed on an ME basis (kcal ME/lb gain), but when balanced on NE, increasing midds had no effect on pig performance. Caloric efficiency and F/G were also poorer ($P < 0.01$) on an ME basis as midds were included in the diets regardless of formulated energy value, but no differences were observed for energetic efficiency on an NE basis (kcal NE/lb gain). This result suggests that the ME values slightly overestimated the energy value of the soybean oil or midds added to the diet and that the NE values provided by IRNA (2004) are a closer approximation of the true energetic value of the feed ingredients, because balancing diets on an NE basis had no effect ($P > 0.16$). For overall economics, feed cost/pig increased ($P < 0.01$) as expected with the NE formulation due to the added soy oil, and increasing midds and balanc-

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[1] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[2] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

ing for NE increased feed cost/lb gain (linear, $P < 0.05$). The main effect of midds level decreased (linear, $P < 0.02$) income over feed cost (IOFC); however, the highest numerical IOFC occurred at both 10% inclusion levels with and without balancing for NE.

In summary, 10% midds can be added to nursery diets without influencing performance. Formulating on an equal NE basis did not improve growth over those pigs fed on a ME basis; however, energetic efficiency values indicate that NE may value the energy content in midds more appropriately.

Key words: ME, NE, nursery pig, wheat middlings

Introduction

Wheat middlings, a by-product of wheat milling, are a common high-fiber ingredient (crude fiber [CF] <9.5%) used in swine diets. Our past research has shown that approximately 10% midds can be fed to nursery pigs without negatively affecting performance. We also found that when calculating caloric efficiencies for diets containing wheat middlings, the NE values provided by INRA (2004) are more accurate in predicting the true energetic value of the diets.[3] This was shown by consistently similar caloric efficiencies regardless of inclusion rate of midds compared with caloric efficiencies derived from ME values, which regularly overestimated the value of midds.

Although research has been conducted with wheat middlings and their effects on nursery pig growth performance when formulated on an ME basis, little is known how performance will be affected when formulated on an equal NE basis. The objective of this study was to determine the effects of increasing dietary midds and equalizing diet NE on growth performance, caloric efficiency, and economics of nursery pigs from 15 to 50 lb.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 210 pigs (PIC 327 × 1050, initially 15.5 lb and 26 d of age) were used in a 29-d growth trial. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a completely randomized design with 7 pigs per pen and 6 replications per treatment. The 5 corn-soybean meal–based diets were: (1) corn-soybean meal diet (positive control); 2) 10% added midds; 3) 20% added midds; 4) Treatment 2 with 1.4% added soybean oil, and 5) Treatment 3 with 2.8% added soybean oil (Table 1). Treatments 4 and 5 were balanced on an NE basis equal to that of the positive control. Feed ingredients were assigned an NE value for the growing pig by INRA (2004). Pigs were fed in a 2-phase feeding program from d 0 to 12 and 12 to 29. All diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill.

[3] De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, and J. L. Nelssen. 2012. Effects of increasing dietary wheat middlings and corn dried distillers grains with solubles in diets for 7- to 23-kg nursery pigs. J. Anim. Sci. 90(Suppl. 2):168 (Abstr.).

Each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and were allowed approximately 3 ft^2/pig. Pig weight and feed disappearance were measured on d 0, 7, 12, 19, 26, and 29 of the trial to determine ADG, ADFI, and F/G.

Wheat midds and complete diet samples were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, NFE, CF, fat, ash, Ca, and P (Tables 2 and 3). Bulk density of the midds and complete diets were also determined. Caloric efficiencies of pigs were determined on both an ME and NE (INRA, 2004[4]) basis. Efficiencies were calculated by multiplying total feed intake by energy in the diet (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed cost/lb gain, revenue/pig, and IOFC were also calculated. Diet costs were determined with the following ingredient costs: corn = 0.14/lb; soybean meal = 0.24/lb; midds = 0.12; soybean oil = .61. Feed cost/pig was determined by total feed intake × cost/lb feed. Feed cost/lb gain was calculated using F/G × feed cost/lb. Revenue/pig was determined by total gain × \$0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit. Contrasts were used to compare midds × fat interactions and linear and quadratic effects of increasing midds (with and without added fat). Contrasts used in analysis examined: (1) midds × balanced NE interaction; (2) midds linear combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20 linear contrast; (3) midds quadratic combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20 quadratic contrast; (4) midds level contrasts the main effect of midds in diets regardless of fat inclusion (compares Treatments 2 and 4 to 3 and 5; (5) balanced NE effect contrasts the main effect of balancing diets on NE (compares Treatments 2 and 3 to 4 and 5). Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

The chemical analysis of the midds (Table 2) indicated that CP and fat levels were slightly below formulated values with CF, Ca, and P all slightly above the formulated values. The analysis of complete diets (Table 3) also showed the expected increases in fiber as midds increased. Bulk density was dramatically influenced by diet formulation, with low density as midds were increased but high density when soybean oil was added.

From d 0 to 12, a midds × fat interaction was observed ($P < 0.01$) for ADFI. This was the result of pigs fed increasing midds having increased feed intake with no added fat but decreased intake when increasing fat was combined with increasing midds. From d 12 to 29, no midds × fat interactions were observed. The main effects of midds (regardless of NE), showed a tendency for decreased ($P < 0.09$) ADG and poorer ($P < 0.001$) F/G. Feed efficiency was similar among pigs fed either 0 or 10% wheat midds but decreased (quadratic, $P < 0.03$) when midds increased to 20% of the diet; however, balancing on a NE basis tended to increase ($P < 0.09$) ADG compared with not balancing for NE when midds were added.

[4] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Overall (d 0 to 29), no midds × fat interactions were observed. Pigs fed increasing midds had a tendency for poorer (linear, $P < 0.06$) F/G and energetic efficiency when expressed on an ME basis (kcal ME/lb gain), but when balanced on NE, increasing midds had no effect on pig performance. Poorer ($P < 0.01$) F/G and caloric efficiency on an ME basis were also found as midds were included in the diets regardless of formulated energy value, but no differences were observed for energetic efficiency on an NE basis (kcal NE/lb gain). This result suggests that the ME values slightly overestimated the energy value of the soybean oil or midds added to the diet, and the NE values provided by IRNA (2004) are a closer approximation of the true energetic value of the feed ingredients, because balancing diets on an NE basis had no effect ($P > 0.16$).

For overall economics, feed cost/pig increased ($P < 0.01$) as expected with the NE formulation due to the added soy oil. Increasing midds and balancing for NE also increased feed cost/lb gain (linear, $P < 0.05$). The main effect of midds decreased (linear, $P < 0.02$) IOFC; however, the highest numerical IOFC occurred at both 10% inclusion levels with and without balancing for NE.

In summary, adding 10% midds to diets for nursery pigs did not affect performance. Formulating on an equal NE basis did not significantly improve growth over those pigs fed on an ME basis. This result is supported by caloric efficiencies tending to worsen when calculated using ME, suggesting that ME values overestimate the value of midds. When calculated on an NE basis, caloric efficiency did not differ with the addition of midds. We should note that although the INRA (2004) NE values are a more accurate energetic value of midds, the actual NE value may change depending on the amount of midds added to the diet, and perhaps the energetic value of midds changes in correlation with its inclusion level in swine diets.

Although using dietary midds reduces performance as expected due to the reduction in diet energy, performance can be restored by formulating on an equal NE basis with the addition of added fat; however, this restored performance increased ($P < 0.01$) feed cost/pig. The economic analysis also showed a decrease (linear, $P < 0.04$) in IOFC as increasing midds were added to the diet, which was primarily due to reduced IOFC ($P < 0.01$) for pigs fed 20% vs.10% midds. The highest numerical IOFC was observed when 10% midds were included in the diet without balancing for NE and the lowest was at 20% midds inclusion; yet, the highest numerical revenue/pig was observed at 10% inclusion of midds with added fat to balance for NE. Notably, soybean oil was used to balance for NE in this experiment, but less expensive fat sources such as choice white grease are available and may influence the economics of balancing on an NE basis. Thus, production and economic goals will determine formulation strategies when using wheat midds in nursery pig diets.

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

	Phase 1					Phase 2				
Wheat middlings, %:	0	10	20	10	20	0	10	20	10	20
Item Fat, %:	0	0	0	1.40	2.80	0	0	0	1.40	2.80
Ingredient, %										
Corn	54.77	47.25	39.73	45.75	36.72	63.74	56.22	48.71	54.72	45.69
Soybean meal (46.5% CP)	29.32	26.86	24.40	26.97	24.62	32.79	30.33	27.87	30.44	28.09
Wheat middlings	---	10.00	20.00	10.00	20.00	---	10.00	20.00	10.00	20.00
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	---	---	---	---	---
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	---	---	---	---	---
Soybean oil	---	---	---	1.40	2.80	---	---	---	1.40	2.80
Monocalcium phosphate (21% P)	0.65	0.50	0.35	0.50	0.35	1.05	0.90	0.75	0.90	0.75
Limestone	0.88	0.95	1.03	0.95	1.03	0.95	1.03	1.10	1.03	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.25	0.29	0.33	0.29	0.33	0.33	0.37	0.41	0.37	0.41
DL-methionine	0.130	0.130	0.130	0.130	0.130	0.135	0.135	0.135	0.135	0.135
L-threonine	0.125	0.140	0.155	0.140	0.155	0.125	0.140	0.155	0.140	0.155
Phytase[2]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100	100	100	100	100	100	100	100	100	100

continued

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

Item	Phase 1					Phase 2				
Wheat middlings, %:	0	10	20	10	20	0	10	20	10	20
Fat, %:	0	0	0	1.40	2.80	0	0	0	1.40	2.80
Standard ileal digestible (SID) amino acids, %										
Lysine	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	62	61	60	61	59	61	60	59	60	59
Methionine:lysine	34	34	34	34	34	34	33	33	33	33
Met & Cys:lysine	58	58	58	58	58	58	58	58	58	58
Threonine:lysine	65	65	65	65	65	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	67	68	67	68	67	67	67	66
Total lysine, %	1.46	1.45	1.45	1.45	1.45	1.42	1.41	1.40	1.41	1.40
ME, kcal/lb[1]	1,500	1,484	1,468	1,515	1,531	1,504	1,487	1,471	1,519	1,534
NE, kcal/lb[2]	1,091	1,063	1,035	1,091	1,091	1,073	1,045	1,017	1,073	1,073
SID lysine:ME, g/Mcal	3.99	4.04	4.08	3.95	3.91	3.86	3.90	3.95	3.82	3.78
CP, %	21.8	21.6	21.5	21.6	21.4	21.2	21.0	20.9	20.9	20.7
Ca, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %	0.66	0.68	0.70	0.68	0.70	0.63	0.65	0.67	0.65	0.67
Available P, %	0.36	0.36	0.36	0.36	0.36	0.30	0.30	0.30	0.30	0.30

[1]Phase 1 diets fed from d 0 to 12 and Phase 2 was fed from d 13 to 29 of the experimental period.
[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

Table 2. Chemical analysis of wheat middlings (as-fed basis)[1]

Item	Analyzed[2]
DM, %	89.38
CP, %	15.30 (15.90)
ADF, %	12.30
NDF, %	35.30
NFE, %[3]	56.10
Crude fiber, %	8.20 (7.00)
Ca, %	0.33 (0.12)
P, %	1.15 (0.93)
Fat, %	3.70 (4.20)
Ash, %	6.08
Particle size, μ	574
Bulk density, lb/bu	23.66

[1] Wheat middlings were from the same batch for both phases of the trial.
[2] Values in parentheses indicate those used in diet formulation.
[3] NFE: nitrogen-free extract.

Table 3. Chemical analysis of diets containing wheat middlings (as-fed basis)[1]

	Phase 1					Phase 2				
Wheat middlings, %	0	10	20	10	20	0	10	20	10	20
Item Fat, %	0	0	0	1.4	2.8	0	0	0	1.4	2.8
DM, %	90.31	89.52	90.07	90.14	90.56	89.91	89.68	89.55	89.69	90.63
CP, %	21.8	22.0	21.2	22.0	21.8	21.5	22.3	21.7	21.6	20.8
ADF, %	4.1	4.1	4.2	3.7	3.3	2.8	4.4	5.1	4.1	4.9
NDF, %	8.0	8.9	10.0	8.5	9.6	9.0	13.2	13.5	10.0	13.0
Crude fiber, %	2.4	2.5	2.9	2.4	2.8	2.2	2.9	3.4	2.8	3.4
NFE, %[2]	55.9	55.4	54.7	55.4	55.2	58.4	55.8	55.8	55.6	55.5
Ca, %	1.74	1.27	1.89	1.45	1.23	1.03	1.11	1.36	1.13	0.99
P, %	0.69	0.70	0.82	0.67	0.71	0.63	0.72	0.74	0.71	0.68
Fat, %	2.5	2.7	2.7	3.5	4.1	2.4	2.6	2.6	3.6	5.3
Ash, %	7.83	6.99	8.47	6.77	6.67	5.19	6.11	6.14	6.09	5.60
Bulk density, lb/bu[3]	54.72	51.31	48.26	50.27	46.48	52.70	47.02	43.54	44.86	41.39

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] NFE: nitrogen-free extract.
[3] Bulk density of a material represents the mass per unit volume.

Table 4. The effects of increasing wheat middlings and NE formulation on nursery pig performance[1]

	Treatment							Midds			
	1	2	3	4	5						
Wheat middlings, %	0	10	20	10	20		Midds × balanced			Midds	Balanced
Item Fat, %	0	0	0	1.4	2.8	SEM	NE interaction[2]	Linear[3]	Quadratic[4]	level[5]	NE effect[6]
d 0 to 12											
ADG, lb	0.56	0.57	0.58	0.61	0.57	0.022	0.33	0.56	0.27	0.49	0.49
ADFI, lb	0.94	0.94	1.03	1.03	0.93	0.031	0.01	0.25	0.36	0.88	0.84
F/G	1.68	1.67	1.80	1.70	1.65	0.085	0.14	0.58	0.72	0.50	0.36
d 12 to 29											
ADG, lb	1.27	1.25	1.19	1.28	1.25	0.025	0.46	0.15	0.37	0.09	0.09
ADFI, lb	1.94	1.90	1.90	1.93	1.98	0.037	0.44	0.91	0.52	0.50	0.16
F/G	1.52	1.52	1.59	1.51	1.58	0.023	0.99	0.03	0.03	0.001	0.54
d 0 to 29											
ADG, lb	0.97	0.97	0.94	1.00	0.97	0.021	0.95	0.41	0.25	0.12	0.13
ADFI, lb	1.52	1.51	1.54	1.55	1.55	0.032	0.54	0.60	0.96	0.71	0.39
F/G	1.56	1.55	1.64	1.55	1.60	0.025	0.34	0.06	0.11	0.01	0.35
Caloric efficiency[7]											
ME	2,346	2,308	2,417	2,358	2,449	36.5	0.82	0.06	0.11	0.01	0.26
NE	1,696	1,643	1,697	1,691	1,728	27.9	0.76	0.64	0.17	0.11	0.16
BW, lb											
d 0	15.15	15.15	15.15	15.15	15.14	0.163	0.98	0.98	0.96	0.95	0.97
d 12	21.82	21.97	22.05	22.41	21.96	0.357	0.46	0.68	0.41	0.60	0.63
d 29	43.40	43.30	42.30	44.19	43.49	0.69	0.83	0.56	0.36	0.23	0.14

[1] A total of 210 pigs (PIC 327 × 1050, initially 15.15 lb and 26 d of age) were used in a 29-d growth trial with 7 pigs per pen and 6 pens per treatment.
[2] Interactive effects of midds level and balanced on an NE basis.
[3] Combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds linear contrast.
[4] Combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds quadratic contrast.
[5] Compares Treatments 2 and 4 vs. 3 and 5.
[6] Compares Treatments 2 and 3 vs. 4 and 5.
[7] Caloric efficiency is expressed as kcal/lb gain.

Table 5. Economics of increasing wheat middlings and NE formulation in nursery pigs[1]

Item	Wheat middlings, % / Fat, %	0 / 0	10 / 0	20 / 0	10 / 1.4	20 / 2.8	SEM	Midds × balanced NE Interaction[2]	Midds Linear[3]	Midds Quadratic[4]	Midds level[5]	Balanced NE effect[6]
d 0 to 12												
Feed cost/pig, $		2.93	2.92	3.13	3.25	2.99	0.098	0.02	0.29	0.34	0.81	0.33
Feed cost/lb gain, $[7]		0.44	0.43	0.45	0.45	0.43	0.015	0.21	0.76	0.92	0.78	0.77
Total revenue/pig, $[8,9]		4.34	4.43	4.49	4.72	4.43	0.170	0.33	0.56	0.27	0.49	0.49
IOFC[10]		1.40	1.51	1.35	1.47	1.44	0.143	0.65	0.96	0.51	0.51	0.89
d 12 to 29												
Feed cost/pig, $		6.24	6.02	5.89	6.32	6.60	0.118	0.09	0.98	0.50	0.52	0.0003
Feed cost/lb gain, $		0.29	0.28	0.29	0.29	0.31	0.005	0.43	0.18	0.09	0.02	0.02
Total revenue/pig, $		14.02	13.86	13.16	14.15	13.87	0.278	0.46	0.15	0.37	0.09	0.09
IOFC		7.78	7.84	7.27	7.83	7.27	0.204	0.99	0.05	0.11	0.010	0.98
d 0 to 29												
Feed cost/pig, $		9.18	8.94	9.03	9.57	9.60	0.200	0.88	0.59	0.94	0.79	0.01
Feed cost/lb gain, $		0.32	0.32	0.33	0.33	0.34	0.005	0.79	0.05	0.15	0.01	0.05
Total revenue/pig, $		18.36	18.30	17.65	18.87	18.30	0.388	0.92	0.42	0.26	0.13	0.13
IOFC		9.19	9.35	8.62	9.30	8.70	0.270	0.81	0.13	0.12	0.02	0.96

[1] A total of 210 pigs (PIC 327 × 1050, initially 15.15 lb BW and 26 d of age) were used in a 29-d growth trial with 7 pigs per pen and 6 pens per treatment.
[2] Feed cost/lb gain = feed cost/lb × F/G, assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton.
[3] One pound of body gain = $0.65/lb.
[4] Total revenue/pig = total gain/pig ×× $0.65.
[5] Income over feed cost = total revenue/pig – feed cost/pig.
[6] Interactive effects of midds level and balanced on an NE basis.
[7] Combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds linear contrast.
[8] Combines Treatments 2 and 4 and 3 and 5 to create a 0, 10, 20% added midds quadratic contrast.
[9] Compares Treatments 2 and 4 vs. 3 and 5.
[10] Compares Treatments 2 and 3 vs. 4 and 5.

The Effects of Soybean Hulls in Corn-Soybean Meal and Corn-Soybean Meal-Dried Distillers Grains with Solubles Diets on Nursery Pig Performance[1,2]

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Summary
Two experiments were conducted to evaluate the effects of soybean hulls in diets with and without corn dried distillers grains with solubles (DDGS) on nursery pig growth performance. In Exp. 1, a total of 600 pigs (PIC C-29 × 359, initially 14.7 lb) were used in a 42-d growth study. Diets contained increasing amounts of soybean hulls (0, 3, 6, 9, or 12%) in either corn-soybean meal or corn-soybean meal-DDGS–based diets (15 and 30% DDGS for Phases 1 and 2, respectively). Pigs were blocked by initial pen weight, gender, and room location, with 10 pigs per pen and 6 replications per treatment. Overall (d 0 to 42), soybean hulls × DDGS interactions (quadratic, $P < 0.05$) were observed for F/G and caloric efficiency on an ME and NE basis. Increasing soybean hulls worsened F/G quadratically ($P < 0.03$) when added to diets without DDGS but linearly ($P < 0.01$) when added to diets with DDGS. Caloric efficiencies improved on an ME and NE basis (quadratic, $P < 0.04$) with increasing soybean hulls in diets without DDGS but did not influence caloric efficiency when added to diets containing DDGS. Adding DDGS to the diet decreased ($P < 0.04$) ADG and ADFI but tended to improve ($P < 0.06$) F/G. Adding soybean hulls to diets containing DDGS further reduced (quadratic, $P < 0.05$) ADG and tended to reduce (quadratic, $P < 0.08$) ADFI, whereas adding soybean hulls to diets without DDGS had no effect on ADG or ADFI.

In Exp. 2, 304 pigs (PIC, 337 × 1050, initially 25.7 lb) were used in a 21-d study. The 8 diets were arranged in a 2 × 4 factorial with increasing soybean hulls (0, 5, 10, or 15%) in either corn-soybean meal or corn-soybean meal-DDGS–based diets (20% DDGS). Pigs were balanced by initial BW and randomly allotted to 1 of 8 dietary treatments with 9 replications per treatment. Overall (d 0 to 21), no soybean hull × DDGS interactions were observed. Increasing soybean hulls tended to worsen (linear, $P < 0.07$) F/G but improved (linear, $P < 0.008$) caloric efficiency on an ME and NE basis. In contrast to the first experiment, the greatest negative effect on F/G (linear, $P < 0.04$) came from adding soybean hulls to diets without DDGS. Adding DDGS to the diets had no effect on growth performance.

These data indicate that feeding up to 15% soybean hulls in diets for nursery pigs does not affect growth rate or feed intake, but worsens F/G and improves caloric efficiency.

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[4] Kalmbach Feeds, Inc, Upper Sandusky, OH.

The improvement in caloric efficiency indicates that published energy values underestimate the energy content of soybean hulls. The influence of DDGS in the diet on the response to soybean hulls varied between trials, indicating that further research is needed to understand potential interactions between high-fiber ingredients such as soybean hulls and DDGS on growth performance and caloric efficiency of nursery pigs.

Key words: DDGS, growth, nursery pig, soybean hulls

Introduction

Soybean hulls are a co-product from solvent extraction processing of whole soybeans and are available to be used in swine diets in the Midwest; however, because soybean hulls are a high-fiber, bulky ingredient with a low energy value (corn NE = 1,202 kcal/lb; soybean hulls NE = 455 kcal/lb; INRA 2004[5]), they may be an underutilized ingredient. A previous study at Kansas State University demonstrated that 5% soybean hulls could be included in conventional corn-soybean–based nursery diets with no negative effects on growth performance, whereas including 10% or greater resulted in decreased performance (see Goehring et al., "The Effects of Soybean Hulls on Nursery Pig Growth Performance" p. 127). The objective of these studies was to evaluate increasing levels of soybean hulls (up to 15%) in diets with or without DDGS on growth performance and caloric efficiency of nursery pigs.

Procedures

The K-State Institutional Animal Care and Use Committee approved the protocols used in these experiments. Experiment 1 was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc. Experiment 2 was conducted at the K-State Segregated Early Weaning Research Facility in Manhattan, KS.

In Exp. 1, a total of 600 pigs (PIC C-29 × 359, initially 14.7 lb BW) were used in a 42-d growth trial. Pens of pigs were blocked by initial pen weight, gender, and room location. Each treatment had 10 replications (pens) with 10 pigs per pen. Each pen had slatted metal floors and was equipped with a 4-hole stainless steel feeder and one nipple-cup waterer for ad-libitum access to feed and water.

Pigs were weaned and fed a common pelleted starter diet for 3 d; thus, d 0 of the experimental period was d 3 postweaning. A 2-phase experimental diet series was used with treatment diets fed from d 0 to 14 for Phase 1 and d 14 to 42 for Phase 2. The treatments included diets containing 0, 3, 6, 9, or 12% finely ground soybean hulls (408 μ) in either corn-soybean meal or corn-soybean meal-DDGS–based diets (15 and 30% DDGS for Phases 1 and 2, respectively). Proximate analysis was conducted by Ward Laboratories, Inc. (Kearny, NE) on the soybean hulls before diet formulation and on the DDGS (Tables 1 and 2). All diets within each phase were formulated on a common standardized ileal digestible (SID) lysine concentration (Tables 3 and 4). The SID lysine levels fed were selected based on the required level for the diets without soybean hulls. Thus, the SID lysine:energy ratio increased as soybean hulls were added to the diet. All

[5] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Phase 1 diets contained 4% fish meal and 10% spray-dried whey. Individual pen weight and feed disappearance were measured on d 0, 7, 14, 21, 28, 35, and 42 to determine ADG, ADFI, and F/G.
All treatment diets were fed in meal form, and the soybean hulls were ground at the K-State Grain Science Feed Mill through a 1/16-in. screen and shipped to Kalmbach Feeds, Inc. for diet manufacturing. Feed samples were collected from each feeder during each phase and combined for a single composite sample of each treatment per phase.

In Exp. 2, a total 304 pigs (PIC, 337 × 1050, initially 25.7 lb) were used in a 21-d growth trial. Pigs were weighed and allotted to 1 of 8 treatments arranged in a 2 × 4 factorial with main effects of DDGS (0 or 20%) and soybean hulls (0, 5, 10, and 15% with 4 or 5 pigs per pen and 9 pens per treatment. Pigs were provided unlimited access to feed and water by way of a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft). All diets were fed in in meal form from d 0 to 21 (Table 5). Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 7, 14, and 21. Soybean hulls and DDGS samples were collected and submitted to Ward Laboratories, Inc. for analysis. Feed samples were collected from each feeder and combined for a single composite sample.

In both studies, data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Contrasts were used to test for soybean hulls × DDGS interactions, main effects of DDGS, and linear and quadratic effects of increasing soybean hulls in both non-DDGS and DDGS diets. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

The analyzed nutrient levels of the soybean hulls used in both experiments were similar to those used in diet formulation, with the exception of a lower Ca value in the soybean hulls for Exp. 2. Analyzed nutrient levels of the DDGS differed, with less CP and fat in the DDGS in Exp. 2 than in Exp. 1. Soybean hulls in diets with and without DDGS reduced the bulk densities of the diets (Table 6) and increased the crude fiber and NDF content (Tables 3, 4, and 5).

For the overall period (d 0 to 42) in Exp. 1, soybean hulls × DDGS interactions (quadratic $P < 0.05$; Table 7) were observed for F/G and caloric efficiency on an ME and NE basis. Increasing soybean hulls worsened F/G quadratically ($P < 0.03$) when added to diets without DDGS and linearly ($P < 0.01$) when added to diets with DDGS. Caloric efficiencies improved on an ME and NE basis (quadratic, $P < 0.04$) with increasing soybean hulls in diets without DDGS but did not influence caloric efficiency when added to diets containing DDGS. Including DDGS in diets decreased ($P < 0.04$) ADG and ADFI and tended to improve ($P < 0.10$) F/G and caloric efficiency on an ME basis but not on an NE basis. Increasing soybean hulls in diets containing DDGS further reduced (quadratic, $P < 0.05$) ADG and tended to decrease (quadratic, $P < 0.08$) ADFI, whereas adding soybean hulls to diets without DDGS had no effect on ADG or ADFI. No significant differences were observed in weight on d 42; nevertheless, pigs fed the diet containing 12% soybean hulls and DDGS were 6.4 lb lighter than pigs fed 12% soybean hulls in diets without DDGS.

Based on the results in Exp. 1, soybean hulls × DDGS interactions occurred for F/G and caloric efficiencies. Feed efficiency worsened with the addition of soybean hulls due to a decrease in dietary energy; however, the improvement in caloric efficiency in diets without DDGS indicates that the energy value of soybean hulls is underestimated by published values when used at low levels in the diet. Contrary to previous research, levels up to 12% soybean hulls could be used without negative effects on ADG and ADFI. Furthermore, DDGS reduced ADG and ADFI but improved F/G while not affecting NE efficiency; therefore, the objective of Exp. 2 was to further evaluate the inclusion of soybean hulls up to 15% with or without DDGS to better understand the interaction of high-fiber ingredients and the impact on ME and NE efficiency.

Contrary to Exp.1, no soybean hulls × DDGS interactions were observed ($P > 0.25$) for the overall data (d 0 to 21) in Exp. 2. Increasing soybean hulls tended to worsen (linear, $P < 0.07$) F/G, but caloric efficiency improved (linear, $P < 0.008$) on an ME and NE basis, suggesting the published energy value for soybean hulls is undervalued. Increasing soybean hulls in diets without DDGS worsened (linear, $P < 0.04$) F/G, but adding DDGS had no effect on growth performance or caloric efficiency on an ME and NE basis.

In conclusion, soybean hulls are a low-energy, low bulk density ingredient that can be used in nursery pig diets up to 5% without affecting feed efficiency or up to 15% of the diet with no changes in gain or feed intake. The improvement in caloric efficiency when soybean hulls were added to the diet suggests that the energy value of soybean hulls is underestimated by published values. A numerical decrease in growth rate was evident when pigs were fed the 30% DDGS with 12% soybean hulls, which could be due to the diet reaching a fiber and NDF level that does not allow pigs to eat enough to meet their energy requirement, potentially due to increased gut fill. These studies suggest that more research is needed to fully understand the influence of combining high levels of high-fiber ingredients and the mechanisms for the decreased growth rate.

Table 1. Chemical analysis of soybean hulls (as-fed basis)

Item	Exp. 1	Exp. 2
Nutrient, %		
DM	91.40	91.71
CP	10.1 (12.2)[1]	13.4 (12.2)
ADF	42	25.2
NDF	58.3	51.2
Crude fiber	34.3 (33.3)	31.8 (33.3)
Ca	0.66 (0.52)	0.11 (0.52)
P	0.10 (0.15)	0.17 (0.15)
Bulk density, lb/bu[2]	37.72	40.25

[1] Values in parentheses indicate those used in diet formulation.

Table 2. Chemical analysis of dried distillers grains with solubles (as-fed basis)

Item	Exp. 1	Exp. 2
Nutrient, %		
DM	91.01	90.77
CP	26.3 (27.2)[1]	29.5 (27.2)
ADF	13.3	16.1
NDF	25.5	27.5
Crude fiber	9.3	8.1
Fat (oil)	11.8 (10.7)	8.7 (10.7)
Ca	0.07 (0.03	0.04 (0.03)
P	0.85 (0.71)	0.87 (0.71)

[1] Values in parentheses indicate those used in diet formulation.

Table 3. Phase 1 diet composition (Exp. 1, as-fed basis)[1]

	Phase 1[2]									
DDGS, %:[3]	0					15				
Item Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Ingredient										
Corn	55.23	52.53	49.76	47.06	44.28	43.14	40.36	37.65	34.95	32.25
Soybean meal, 46.5% CP	28.19	27.92	27.73	27.46	27.27	25.54	25.35	25.08	24.81	24.54
Soybean hulls	--	3.00	6.00	9.00	12.00	--	3.00	6.00	9.00	12.00
DDGS	--	--	--	--	--	15.00	15.00	15.00	15.00	15.00
Select menhaden fish meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Spray dried whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Monocalcium P, 21% P	0.50	0.50	0.50	0.50	0.50	0.15	0.15	0.15	0.15	0.15
Limestone	0.83	0.80	0.76	0.72	0.69	1.00	0.98	0.95	0.91	0.88
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.230	0.228	0.223	0.220	0.215	0.260	0.255	0.253	0.250	0.248
L-threonine	0.123	0.128	0.133	0.138	0.143	0.050	0.055	0.060	0.065	0.070
L-tryptophan	0.130	0.133	0.135	0.138	0.138	0.088	0.090	0.093	0.095	0.098
Ronozyme CT (10,000)[4]	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 3. Phase 1 diet composition (Exp. 1, as-fed basis)[1]

	Phase 1[2]									
DDGS, %:[3]	0					15				
Item / Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Calculated analysis										
Standardized ileal digestible (SID) amino acids, %										
Lysine	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Isoleucine:lysine	63	62	62	62	62	65	65	65	65	65
Leucine:lysine	128	127	126	125	124	143	142	141	140	139
Methionine:lysine	35	35	35	35	36	32	32	32	32	33
Met & Cys:lysine	58	58	58	58	58	58	58	58	58	58
Threonine:lysine	65	65	66	66	65	65	65	65	65	65
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	69	69	69	68	68	73	73	73	72	72
Total lysine, %	1.46	1.47	1.47	1.48	1.49	1.49	1.49	1.50	1.51	1.52
ME, kcal/lb	1,504	1,484	1,463	1,443	1,422	1,507	1,486	1,466	1,445	1,425
SID lysine:ME, g/Mcal	3.98	4.05	4.13	4.21	4.29	3.97	4.05	4.12	4.20	4.28
CP, %	21.9	21.9	22.0	22.0	22.0	23.7	23.7	23.7	23.8	23.8
Crude fiber, %	2.3	3.2	4.2	5.1	6.0	1.9	2.9	3.8	4.7	5.7
ADF, %[5]	3.1	4.2	5.3	6.4	7.6	5.0	6.2	7.3	8.4	9.5
NDF, %[6]	7.8	9.2	10.6	12.0	13.5	11.6	13.0	14.4	15.8	17.2
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1] A total of 600 nursery pigs (PIC C-29 × 359, initially 14.7 lb) were used in a 42-d growth trial with 6 replications per treatment.
[2] Phase 1 diets were fed from d 0 to 14.
[3] DDGS: dried distillers grains with solubles.
[4] Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 840 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Soybean hulls ADF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[6] Soybean hulls NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 4. Phase 2 diet composition (Exp. 1, as-fed basis)[1]

	Phase 2[2]									
DDGS, %:[3]	0					30				
Item / Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Ingredient										
Corn	63.94	61.03	58.35	55.60	52.93	39.74	36.98	34.20	31.44	28.73
Soybean meal (46.5% CP)	32.71	32.67	32.40	32.21	31.94	27.34	27.15	26.96	26.77	26.50
Soybean hulls	--	3.00	6.00	9.00	12.00	--	3.00	6.00	9.00	12.00
DDGS	--	--	--	--	--	30.00	30.00	30.00	30.00	30.00
Monocalcium P (21% P)	1.05	1.05	1.05	1.05	1.05	0.35	0.35	0.35	0.35	0.35
Limestone	0.95	0.89	0.83	0.77	0.71	1.35	1.30	1.28	1.23	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.333	0.323	0.320	0.315	0.313	0.395	0.390	0.385	0.380	0.378
L-threonine	0.130	0.138	0.145	0.150	0.158	0.005	0.008	0.010	0.013	0.015
L-tryptophan	0.125	0.130	0.135	0.138	0.140	0.048	0.050	0.053	0.055	0.058
Ronozyme CT (10,000)[4]	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 4. Phase 2 diet composition (Exp. 1, as-fed basis)[1]

	Phase 2[2]									
DDGS, %:[3]	0					30				
Item — Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12
Calculated analysis										
Standardized ileal digestible (SID) amino acids,%										
Lysine	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	61	62	61	61	61	66	66	66	66	66
Leucine:lysine	129	128	127	126	125	160	159	158	157	156
Methionine:lysine	33	33	34	34	35	29	29	29	29	29
Met & Cys:lysine	58	58	58	58	59	59	58	58	58	58
Threonine:lysine	63	63	63	63	63	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	68	67	67	77	77	76	76	76
Total lysine, %	1.42	1.42	1.43	1.44	1.44	1.47	1.48	1.49	1.50	1.50
ME, kcal/lb	1,505	1,48	1,465	1,445	1,424	1,510	1,489	1,469	1,448	1,428
SID lysine:ME, g/Mcal	3.86	3.93	4.00	4.07	4.15	3.85	3.92	3.99	4.06	4.14
CP, %	21.13	21.23	21.25	21.29	21.31	24.67	24.71	24.75	24.79	24.80
Crude fiber, %	2.7	3.6	4.5	5.5	6.4	1.9	2.9	3.8	4.7	5.7
ADF, %[5]	3.6	4.7	5.8	6.9	8.1	7.5	8.6	9.7	10.9	12.0
NDF, %[6]	9.1	10.5	11.9	13.3	14.7	16.6	18.0	19.5	20.9	22.3
Ca, %	0.69	0.68	0.67	0.66	0.65	0.69	0.69	0.69	0.69	0.69
P, %	0.63	0.62	0.62	0.61	0.61	0.59	0.58	0.58	0.57	0.57
Available P, %	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

[1] A total of 600 nursery pigs (PIC C-29 × 359, initially 14.7 lb) were used in a 42-d growth trial with 6 replications per treatment.
[2] Phase 2 diets were fed from d 14 to 42.
[3] DDGS: dried distillers grains with solubles.
[4] Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 840 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Soybean hulls ADF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[6] Soybean hulls NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 5. Diet composition (Exp. 2, as-fed basis)[1]

DDGS,%[2]	0				20			
Item — Soybean hulls, %	0	5	10	15	0	5	10	15
Ingredient								
Corn	64.42	59.84	55.16	50.72	48.25	43.82	39.21	34.48
Soybean meal (46.5% CP)	32.08	31.73	31.47	30.97	28.55	28.05	27.71	27.52
Soybean hulls	-	5.00	10.00	15.00	-	5.00	10.00	15.00
DDGS	-	-	-	-	20.00	20.00	20.00	20.00
Monocalcium P (21% P)	1.05	1.05	1.05	1.05	0.6	0.6	0.6	0.6
Limestone	1.00	0.93	0.88	0.80	1.25	1.18	1.13	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCL	0.328	0.320	0.310	0.308	0.368	0.365	0.358	0.345
DL-methionine	0.125	0.130	0.140	0.150	0.043	0.045	0.053	0.060
L-threonine	0.125	0.123	0.125	0.130	0.065	0.070	0.073	0.075
Phyzyme 600[3]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids,%								
Lysine	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Isoleucine:lysine	61	61	61	61	65	65	65	65
Leucine:lysine	129	128	127	125	151	149	147	146
Methionine:lysine	33	33	34	34	30	30	30	31
Met & Cys:lysine	58	58	58	58	58	58	58	58
Threonine:lysine	63	63	63	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	67	67	74	74	73	73
Total lysine, %	1.39	1.41	1.42	1.43	1.43	1.44	1.46	1.47
ME, kcal/lb	1,503	1,458	1,413	1,368	1,506	1,461	1,416	1,371
SID lysine: ME, g/Mcal	3.80	3.92	4.05	4.18	3.80	3.91	4.04	4.17
CP, %	20.9	20.9	21.0	21.0	23.2	23.2	23.3	23.4
Crude fiber, %	2.7	4.2	5.8	7.3	2.2	3.7	5.3	6.8
ADF, %[4]	3.5	5.4	7.3	9.2	6.2	8.0	9.9	11.8
NDF, %[5]	9.0	11.4	13.7	16.1	14.1	16.4	18.8	21.1
Ca, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
P, %	0.62	0.61	0.61	0.60	0.60	0.59	0.58	0.58
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

[1] A total of 304 pigs (PIC, 337 × 1050, initially 25.7 lb) were used in a 21-d growth trial with 9 replications per treatment.
[2] DDGS: dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with release of 0.10% available P.
[4] Soybean hulls ADF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[5] Soybean hulls NDF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 6. Bulk density of experimental diets (Exp. 2) (as-fed basis)[1]

		Treatments							
	DDGS, %:[2]	0				20			
Item	Soybean hulls, %:	0	5	10	15	0	5	10	15
Bulk density, lb/bu		58.2	56.7	54.1	49.7	54.5	51.7	49.2	50.3

[1] Diet samples collected from the tops of each feeder during each phase. Bulk density was not measured in Exp. 1.
[2] DDGS: dried distillers grains with solubles.

Table 7. The effects of soybean hulls in corn-soybean meal and corn-soybean meal-dried distillers grains with solubles (DDGS) nursery diets (Exp. 1)[1]

												Probability, $P<$			
												Soy hulls w/out DDGS		Soybean hulls with DDGS	
DDGS, %[2]:	-					+									
Item Soybean hulls, %:	0	3	6	9	12	0	3	6	9	12	SEM	Linear	Quadratic	Linear	Quadratic
d 0 to 42															
ADG, lb	1.25	1.20	1.21	1.22	1.24	1.19	1.20	1.22	1.18	1.09	0.036	0.99	0.28	0.08	0.05
ADFI, lb	1.89	1.85	1.89	1.93	1.88	1.75	1.77	1.87	1.83	1.68	0.070	0.81	0.93	0.74	0.08
F/G, lb[3]	1.51	1.54	1.56	1.58	1.51	1.48	1.47	1.53	1.55	1.53	0.024	0.47	0.03	0.01	0.46
Caloric efficiency[4]															
ME[3]	2,274	2,287	2,289	2,286	2,157	2,227	2,189	2,248	2,249	2,190	35.7	0.005	0.04	0.89	0.46
NE[3]	1,628	1,627	1,618	1,606	1,505	1,615	1,579	1,610	1,601	1,549	25.3	0.002	0.04	0.17	0.45
BW, lb															
d 0	14.7	14.4	14.5	14.7	14.7	14.6	14.6	14.7	14.5	14.5	0.92	0.89	0.84	0.91	0.95
d 42	67.2	64.8	65.4	66.7	66.9	64.4	65.2	66.0	64.3	60.5	2.36	0.88	0.51	0.25	0.19

[1] A total of 600 nursery pigs (PIC C-29 × 359, initially 14.7 lb) were used in a 42-d growth trial with 10 replications per pen.

[2] Phase 1 = 15% DDGS, Phase 2 = 30% DDGS.

[3] Soybean hulls level × DDGS interaction, quadratic, $P < 0.05$.

[4] Caloric efficiency is express as kcal/lb gain.

Table 8. Main effects of soybean hulls and dried distillers grains with solubles (DDGS) (Exp. 1)[1]

										Probability, *P*<		
	Soybean hulls, %						DDGS[2]			Soybean hulls		
Item	0	3	6	9	12	SEM	-	+	SEM	Linear	Quadratic	DDGS
d 0 to 42												
ADG, lb	1.22	1.20	1.22	1.20	1.17	0.026	1.22	1.18	0.02	0.23	0.55	0.04
ADFI, lb	1.82	1.81	1.88	1.88	1.78	0.051	1.89	1.78	0.03	0.95	0.20	0.02
F/G	1.49	1.51	1.55	1.57	1.52	0.018	1.54	1.51	0.01	0.03	0.04	0.06
Caloric efficiency[3]												
ME	2,251	2,238	2,268	2,267	2,173	25.2	2,258	2,220	16.0	0.12	0.05	0.10
NE	1,622	1,603	1,614	1,603	1,527	17.7	1,597	1,591	11.3	0.002	0.05	0.73
BW, lb												
d 0	14.7	14.5	14.6	14.6	14.6	0.62	14.6	14.6	0.41	0.98	0.92	0.92
d 42	65.8	65.0	65.7	65.5	63.7	1.67	66.2	64.1	1.06	0.47	0.65	0.16

[1] A total of 600 nursery pigs (PIC C-29 × 359, initially 14.7 lb) were used in a 42-d growth trial with 10 replications per pen.
[2] Phase 1 = 15% DDGS, Phase 2 = 30% DDGS.
[3] Caloric efficiency is express as kcal/lb gain.

Table 9. The effects of soybean hulls in corn-soybean meal and corn-soybean meal-dried distillers grains with solubles (DDGS) diets (Exp. 2)[1]

	DDGS, %									Probability, *P*<			
	0				20					Soybean hulls w/out DDGS		Soybean hulls with DDGS	
Item Soybean hulls, %:	0	5	10	15	0	5	10	15	SEM[2]	Linear	Quadratic	Linear	Quadratic
d 0 to 21													
ADG	1.17	1.18	1.16	1.13	1.13	1.15	1.14	1.10	0.032	0.27	0.53	0.43	0.36
ADFI	1.81	1.82	1.83	1.82	1.78	1.80	1.79	1.75	0.053	0.82	0.82	0.61	0.50
F/G	1.54	1.54	1.59	1.61	1.57	1.57	1.57	1.59	0.027	0.04	0.58	0.61	0.64
Caloric efficiency[3]													
ME	2,319	2,262	2,273	2,253	2,365	2,317	2,250	2,234	38.7	0.27	0.62	0.007	0.66
NE	1,657	1,600	1,590	1,558	1,707	1,656	1,590	1,560	27.3	0.01	0.63	0.0001	0.68
BW, lb													
d 0	26.0	25.6	25.6	25.6	25.7	25.6	25.7	25.7	0.59	0.66	0.78	0.98	0.97
d 21	50.6	50.5	50.4	49.3	49.5	49.7	50.4	48.8	1.05	0.40	0.62	0.74	0.35

[1] A total of 304 pigs (PIC, 337 × 1050, initially 25.7 lb) were used in a 21-d growth trial with 9 replications per treatment.
[2] No soybean hulls × DDGS interactions, $P > 0.25$.
[3] Caloric efficiency is express as kcal/lb gain.

Table 10. Main effects of soybean hulls in corn-soybean meal and corn-soybean meal-dried distillers grains with solubles (DDGS) diets (Exp. 2)[1]

	Soybean hulls, %					DDGS			Probability, $P<$		
									Soybean hulls		
Item	0	5	10	15	SEM	0	20%	SEM	Linear	Quadratic	DDGS
d 0 to 21											
ADG	1.15	1.17	1.15	1.11	0.022	1.16	1.13	0.02	0.18	0.28	0.17
ADFI	1.79	1.81	1.81	1.78	0.036	1.82	1.78	0.03	0.85	0.52	0.26
F/G	1.56	1.56	1.57	1.60	0.018	1.57	1.58	0.01	0.07	0.47	0.74
Caloric efficiency[2]											
ME	2,342	2,289	2,261	2,244	25.8	2,277	2,291	18.3	0.008	0.50	0.59
NE	1,682	1,628	1,590	1,559	18.2	1,601	1,628	12.9	0.0001	0.53	0.15
BW, lb											
d 0	25.8	25.6	25.7	25.6	0.39	25.7	25.7	0.30	0.77	0.82	0.94
d 21	50.0	50.1	50.4	49.0	0.70	50.2	49.6	0.51	0.41	0.29	0.40

[1] A total of 304 pigs (PIC, 337 × 1050, initially 25.7 lb) were used in a 21-d growth trial with 9 replications per treatment.
[2] Caloric efficiency is express as kcal/lb gain.

The Effects of Soybean Hulls on Nursery Pig Growth Performance

D. L. Goehring, M. D. Tokach, J. M. DeRouchey, J. L. Nelssen, R. D. Goodband, and S. S. Dritz[1]

Summary

Two experiments were conducted to evaluate the effects of soybean hulls on growth performance of nursery pigs. In both experiments, pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 6 replications per treatment. In Exp. 1, a total of 210 nursery pigs (PIC, 337 × 1050, initially 14.7 lb and 28 d of age) were used in a 34-d experiment. Diets contained increasing amounts of soybean hulls (0, 5, 10, 15, and 20%) and were not balanced for energy. Overall (d 0 to 34), pigs fed increasing soybean hulls had decreased ADG (linear, $P < 0.01$) and poorer F/G (linear, $P < 0.001$), with no change in ADFI ($P > 0.23$). Despite the linear response, the greatest decreases in pig performance were observed as soybean hulls were added at 10% or greater of the diet; those fed only 5% of the diet were similar to control pigs.

In Exp. 2, 210 nursery pigs (PIC, 337 × 1050, initially 29.9 lb) were used in a 20-d study. Pigs were fed a common diet for 14 d after weaning. The 5 corn-soybean meal–based diets were arranged in a 2 × 2 + 1 factorial, including a corn-soybean meal control diet without soybean hulls and diets containing 10 or 20% soybean hulls either balanced on an NE basis or not. The diets balanced for NE contained 3.6 and 7.15% added fat (soybean oil) in the 10 and 20% soybean hull diets to achieve the same NE value as the control diet.

Overall (d 0 to 20), pigs fed increasing soybean hulls had decreased ADG (linear, $P < 0.01$) regardless of formulation method; however, pigs fed increasing amounts of soybean hulls without added fat were similar in ADFI but had poorer F/G (linear, $P < 0.001$). Pigs fed diets containing soybean hulls balanced for NE had decreased ADFI ($P < 0.001$) but improved F/G ($P < 0.001$) compared with pigs fed soybean hulls with no added fat, resulting in F/G similar to the control-fed pigs.

In summary, soybean hulls can be included in nursery pig diets up to 5% with no negative effects on ADG, ADFI, and F/G. Higher amounts, up to 20% soybean hulls, can be included in nursery pig diets with F/G similar to pigs fed corn-soybean diets if diets are formulated on an NE basis, but there are reductions in ADFI and ADG.

Key words: NE, nursery pig, soybean hulls

Introduction

Soybean hulls are a readily available co-product of the solvent extraction of whole soybeans that could be used in swine diets across the Midwest, but because of soybean hulls' low energy value (corn NE = 1,202 kcal/lb; soybean hulls NE = 455 kcal/lb;

INRA 2004[1]) and a lack of research, few swine producers use soybean hulls in nursery pig diets. When including soybean hulls in corn-soybean meal–based diets, the energy content will decrease unless diets are balanced for energy by including added fat.

Due to limited research on added soybean hulls in nursery diets, the first objective of these two studies was to evaluate the effects of increasing soybean hulls (0 to 20%) on nursery pig performance. Our second objective was to determine whether balancing diets on an NE basis by adding dietary fat influenced the pigs' response to soybean hulls.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. Both studies were conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

Soybean hull samples were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, crude fiber, Ca, and P (Table 1). Bulk density of the soybean hulls (Table 1) and complete diets were also determined (Tables 2 and 3).

In Exp. 1, a total of 210 pigs (PIC 327 × 1050, initially 14.7 lb and 28 d of age) were used. Pigs were allotted to pens by initial BW, and pens were assigned to 1 of 5 treatments in a completely randomized design with 7 pigs per pen and 6 replications per treatment. Experimental diets contained increasing amounts of soybean hulls: 0, 5, 10, 15, or 20% and were not balanced to a constant NE (Table 2). Pig weight and feed disappearance were measured on d 0, 7, 13, 20, 27, and 34 of the trial to determine ADG, ADFI, and F/G. All diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill in Manhattan, KS.

In Exp. 2, a total of 210 pigs (PIC 327 × 1050, initially 29.9 lb) were used in a 20-d growth trial to determine the effects of increasing dietary soybean hulls with or without a constant NE level on nursery pig performance. All pigs were initially fed a starter diet followed by a Phase 2 diet for 14 d after weaning. Pigs were allotted to pens by initial BW, and pens were assigned to 1 of 5 treatments in a completely randomized design with 7 pigs per pen and 6 replications per treatment. The 5 treatment diets included a control diet without soybean hulls and diets containing 10% or 20% soybean hulls either balanced on an NE-basis or not. The diets balanced for NE contained 3.6 and 7.15% added soybean oil in the 10 and 20% soybean hull diets to achieve the same NE as the control diet (Table 3). Pig weight and feed disappearance were measured on d 0, 6, 13, and 20 of the trial to determine ADG, ADFI, and F/G. All diets were fed in meal form and were prepared at the K-State Animal Science Feed Mill.

In both studies, each pen contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig.

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[1] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez, and G. Tran, eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In Exp. 1, contrasts were used to compare linear and quadratic effects of increasing soybean hulls. Contrasts in Exp. 2 were used to compare linear and quadratic effects of increasing soybean hulls with and without balancing for NE. In addition, diet formulation method and soybean hull level effects were also tested, along with interactions between soybean hulls and diet formulation method. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

In Exp. 1, increasing soybean hulls resulted in higher fiber and NDF and lower energy and decreased bulk densities compared with the corn-soybean meal control diet (Table 2). For every dietary period, pigs fed increasing soybean hulls had decreased (linear, $P < 0.01$) ADG and poorer (linear, $P < 0.001$) F/G, with no change ($P > 0.21$) in ADFI. Despite the linear response for ADG and F/G, much of this effect was observed in pigs fed 10% soybean hulls or greater (Table 4). Although F/G became worse, increasing soybean hulls in the diet improved (linear, $P < 0.02$) caloric efficiency on an NE basis. Nursery pigs will attempt to consume feed to meet an energy requirement. Because of the low bulk density and potential for increased gut fill caused by high amounts of soybean hulls, pigs in this experiment were unable to maintain energy intake on lower-energy diets containing more than 5% soybean hulls.

Based on the results in Exp. 1, 5% soybean hulls could be used with no negative effects on growth performance, but using more than 5% resulted in poorer F/G and ADG. Therefore, the objective of Exp. 2 was to determine if balancing diets containing soybean hulls on an NE basis with added fat could restore performance similar to corn-soybean diets.

Overall (d 0 to 20), pigs fed increasing soybean hulls had decreased ADG (linear, $P < 0.003$), whether or not diets were formulated to a constant NE. When diets were not balanced for NE (no added fat), ADFI did not change, but poorer (linear, $P < 0.0001$) F/G and caloric efficiency on an NE basis ($P < 0.05$) were observed. When adding fat to diets containing soybean hulls to increase NE, F/G was similar to pigs fed the control diet and improved F/G ($P < 0.0001$) compared with pigs fed diets not balanced for NE. Overall, increasing soybean hulls decreased (linearly, $P < 0.0002$) ADFI. The fact that pigs fed diets balanced on a NE basis were identical to the control-fed pigs in F/G suggests that the NE value used for the soybean hulls in this study was appropriate.

In conclusion, soybean hulls are a low-energy, low bulk density ingredient that can be used in nursery pig diets at 5% with no negative effects on growth performance. Conversely, high amounts (greater than 5%) of soybean hulls can restrict performance, probably because of increased fiber and low diet bulk density. Formulating diets on an NE basis by adding fat can result in similar F/G but still fail to maintain ADG and ADFI. These studies suggest that more research is needed to understand how low-energy ingredients such as soybean hulls can potentially affect gut fill, feed intake, and growth.

Table 1. Chemical analysis soybean hulls (as-fed basis)

Item	Exp. 1	Exp. 2
DM, %	91.9	90.6
CP, %	11.2 (11.1)[1]	10.2 (11.1)
ADF, %	44.0	42.0
NDF, %	59.0	56.2
Crude fiber, %	34.2 (33.3)	33.3 (33.3)
Ca, %	0.64 (0.52)	0.65 (0.52)
P, %	0.11 (0.15)	0.11 (0.15)
Bulk density, lb/bu	27.9	34.5

[1] Values in parentheses indicate those used in diet formulation.

Table 2. Diet composition (Exp. 1, as-fed basis)

	Phase 1[1]					Phase 2[2]				
Item Soybean hulls, %	0	5	10	15	20	0	5	10	15	20
Ingredient										
Corn	54.70	50.10	45.50	40.90	36.29	63.75	59.07	54.39	49.71	45.04
Soybean meal, 46.5% CP	29.40	29.06	28.71	28.36	28.02	32.79	32.53	32.26	31.99	31.72
Soybean hulls	--	5.00	10.00	15.00	20.00	--	5.00	10.00	15.00	20
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	--	--	--	--	--
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	--	--	--	--	--
Monocalcium P, 21% P	0.65	0.65	0.65	0.65	0.65	1.05	1.05	1.05	1.05	1.05
Limestone	0.88	0.81	0.75	0.69	0.63	0.95	0.89	0.83	0.77	0.71
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.248	0.243	0.238	0.233	0.228	0.330	0.323	0.315	0.308	0.300
L-threonine	0.120	0.130	0.140	0.150	0.160	0.130	0.138	0.145	0.153	0.160
L-tryptophan	0.130	0.135	0.140	0.145	0.150	0.125	0.130	0.135	0.140	0.145
Phytase 600[3]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 2. Diet composition (Exp. 1, as-fed basis)

		Phase 1[1]					Phase 2[2]				
Item	Soybean hulls, %	0	5	10	15	20	0	5	10	15	20
Calculated analysis											
Standardized ileal digestible (SID) amino acids, %											
Lysine		1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine		62	62	62	62	62	61	61	61	61	61
Leucine:lysine		127	125	124	122	121	129	127	126	124	123
Methionine:lysine		34	34	35	35	35	33	34	34	34	34
Met & Cys:lysine		58	58	58	58	58	58	58	58	58	57
Threonine:lysine		65	65	65	65	65	63	63	63	63	63
Tryptophan:lysine		18	18	18	17	17	17	18	18	18	18
Valine:lysine		68	68	67	67	66	68	68	67	67	66
Total lysine, %		1.46	1.47	1.48	1.49	1.50	1.42	1.43	1.44	1.45	1.46
ME, kcal/lb		1,500	1,455	1,410	1,365	1,320	1,503	1,458	1,413	1,368	1,323
SID lysine:ME, g/Mcal		3.99	4.12	4.25	4.39	4.54	3.86	3.98	4.11	4.24	4.39
CP, %		21.8	21.8	21.8	21.8	21.9	21.1	21.2	21.2	21.3	21.3
Crude fiber,%		2.4	3.9	5.5	7.0	8.6	2.7	4.2	5.8	7.3	8.9
ADF[4]		3.1	5.0	6.9	8.7	10.6	3.6	5.4	7.3	9.2	11.1
NDF[4]		7.9	10.2	12.6	14.9	17.3	9.0	11.4	13.7	16.1	18.4
Ca, %		0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
P, %		0.66	0.65	0.64	0.63	0.62	0.63	0.62	0.61	0.60	0.60
Available P, %		0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42
Bulk density, lb/bu[5]		62.9	59.7	55.5	52.5	51.2	62.3	60.0	55.8	56.0	51.7

[1] Phase 1 diets were fed from d 0 to 13.
[2] Phase 2 diets were fed from d 13 to 34.
[3] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO) provided 231 phytase units (FTU)/lb, with a release of 0.10% available P.
[4] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[5] Diet samples collected from the top of each feeder during each phase.

Table 3. Diet composition (Exp. 2, as-fed basis)

Item	Soybean hulls, % / NE, kcal/lb:	0 / 1,073	10 / 1,001	20 / 930	10 / 1,073	20 / 1,073
Ingredient						
Corn		63.75	54.39	45.03	50.49	37.29
Soybean meal, 46.5% CP		32.79	32.26	31.72	32.55	32.30
Soybean hulls		--	10.00	20.00	10.00	20.00
Soybean oil		--	--	--	3.60	7.15
Monocalcium P, 21% P		1.05	1.05	1.05	1.05	1.05
Limestone		0.95	0.83	0.71	0.83	0.71
Salt		0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.25	0.25	0.25	0.25	0.25
Trace mineral premix		0.15	0.15	0.15	0.15	0.15
L-lysine HCl		0.330	0.315	0.300	0.315	0.300
DL-methionine		0.130	0.150	0.170	0.155	0.180
L-threonine		0.125	0.135	0.145	0.135	0.145
Phytase 600[1]		0.125	0.125	0.125	0.125	0.125
Total		100.0	100.0	100.0	100.0	100.0

continued

Table 3. Diet composition (Exp. 2, as-fed basis)

Item	Soybean hulls, % / NE, kcal/lb:	0 / 1,073	10 / 1,001	20 / 930	10 / 1,073	20 / 1,073
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine		1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine		61	61	61	61	60
Leucine:lysine		129	126	123	124	119
Methionine:lysine		33	34	35	34	35
Met & Cys:lysine		58	58	58	58	58
Threonine:lysine		63	63	63	63	63
Tryptophan:lysine		17	18	18	17	17
Valine:lysine		68	67	66	67	65
Total lysine, %		1.42	1.44	1.46	1.44	1.46
ME, kcal/lb		1,503	1,413	1,323	1,495	1,485
NE, kcal/lb		1,073	1,001	930	1,073	1,073
SID lysine:ME, g/Mcal		3.86	4.11	4.39	3.88	3.91
CP, %		21.1	21.2	21.3	21.0	20.9
Crude fiber,%		2.7	5.8	5.7	8.9	8.7
ADF[2]		3.6	7.3	7.2	11.1	10.9
NDF[2]		9.0	13.7	13.4	18.4	17.7
Ca, %		0.69	0.69	0.69	0.69	0.69
P, %		0.63	0.61	0.60	0.60	0.58
Available P, %		0.42	0.42	0.42	0.42	0.42
Bulk density, lb/bu[3]		62.5	57.7	53.2	54.2	50.4

[1] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with release of 0.10% available P.

[2] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

[3] Diet samples collected from the top of each feeder during each phase.

Table 4. The effects of soybean hulls in nursery diets on nursery pig performance (Exp. 1)[1]

	Soybean hulls, %						Probability, *P*<	
Item	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 13								
ADG, lb	0.48	0.46	0.44	0.41	0.39	0.026	0.01	0.79
ADFI, lb	0.72	0.71	0.76	0.71	0.66	0.030	0.21	0.16
F/G	1.49	1.52	1.70	1.73	1.71	0.062	0.01	0.27
Caloric efficiency[2]								
ME	2,264	2,263	2,468	2,453	2,375	91.9	0.17	0.29
NE	1,646	1,627	1,759	1,728	1,654	65.0	0.58	0.27
d 13 to 34								
ADG, lb	1.28	1.28	1.26	1.23	1.12	0.032	0.01	0.07
ADFI, lb	1.98	1.96	2.02	2.01	1.87	0.051	0.30	0.10
F/G	1.55	1.53	1.61	1.63	1.66	0.024	0.01	0.62
Caloric efficiency								
ME	2,328	2,247	2,308	2,289	2,272	34.2	0.52	0.70
NE	1,662	1,586	1,610	1,577	1,547	23.6	0.004	0.68
d 0 to 34								
ADG, lb	0.97	0.97	0.95	0.91	0.84	0.024	0.01	0.11
ADFI, lb	1.50	1.48	1.54	1.51	1.41	0.041	0.23	0.10
F/G	1.54	1.53	1.62	1.65	1.67	0.024	0.0001	0.88
Caloric efficiency								
ME	2,315	2,247	2,331	2,314	2,284	34.0	0.96	0.85
NE	1,658	1,592	1,633	1,600	1,561	23.5	0.02	0.84
BW, lb								
d 0	14.62	14.60	14.85	14.60	14.62	0.13	1.00	0.38
d 13	20.86	20.62	20.59	20.17	19.61	0.37	0.02	0.47
d 34	47.67	47.55	47.02	46.02	43.22	0.87	0.01	0.09

[1] A total of 210 nursery pigs (PIC 337 × 1050, initially 14.7 lb) were used in a 34-d study with 7 pigs per pen and 6 replications per treatment.
[2] Caloric efficiency is expressed as kcal/lb gain.

Table 5. The effects of soybean hulls and diet NE on nursery pig performance[1]

Item	NE, kcal/lb:	Soybean hulls, % 0	10	20	10	20	SEM[2]	Soybean hulls[3] Linear	Quadratic	Soybean hulls + oil[4] Linear	Quadratic	NE effect
		1,073	1,001	930	1,073	1,073						
d 0 to 20												
ADG, lb		1.50	1.46	1.38	1.48	1.40	0.021	0.0004	0.39	0.003	0.28	0.32
ADFI, lb		2.36	2.45	2.41	2.31	2.22	0.038	0.33	0.21	0.02	0.68	0.0002
F/G		1.57	1.67	1.75	1.56	1.58	0.019	0.0001	0.61	0.62	0.49	0.0001
Caloric efficency[5]												
ME		2,365	2,402	2,393	2,364	2,419	28.6	0.49	0.52	0.19	0.43	0.96
NE		1,687	1,676	1,629	1,673	1,698	20.2	0.05	0.48	0.70	0.43	0.11
BW, lb												
d 0		29.9	29.9	29.9	29.9	29.8	5.65	0.54	0.70	0.58	0.81	0.84
d 20		59.9	59.2	57.4	59.5	57.9	8.54	0.57	0.42	0.74	1.00	0.81

[1] A total of 210 nursery pigs (PIC 337 × 1050, initially 29.9) were used in a 20-d study with 7 pigs per pen and 6 replications per treatment.
[2] Soybean hulls × NE interaction, $P > 0.09$.
[3] Comparisons of 0, 10, and 20% added soybean hulls without constant NE value.
[4] Comparison of 0, 10, and 20% with constant NE value.
[5] Caloric efficiency is expressed as kcal/lb gain.

The Effects of Dietary Soybean Hulls, Particle Size, and Diet Form on Nursery Pig Performance[1,2]

D. L. Goehring, M. D. Tokach, J. M. DeRouchey, J. L. Nelssen, R. D. Goodband, S. S. Dritz[3], and B. W. James[4]

Summary

A total of 1,100 nursery pigs (PIC C-29 × 359, initially 15.0 lb BW) were used in a 42-d growth trial to determine the effects of increasing soybean hulls (10 or 20%) and soybean hull particle size (unground or ground) in nursery pig diets fed in both meal and pelleted forms. The average particle size of the unground and ground soybean hulls were 617 and 398 μ, respectively. Pens of pigs (5 barrows and 5 gilts) were balanced by initial BW and randomly allotted to 1 of 8 treatments with 11 replications per treatment. A 2-phase diet series was used with treatment diets fed from d 0 to 14 for Phase 1 and d 14 to 42 for Phase 2. Treatments were arranged in a 2 × 2 × 2 factorial with main effects of 10 or 20% unground or finely ground soybean hulls with diets in pelleted or meal form. For individual phases and overall (d 0 to 42), no soybean hull × particle size × diet form or particle size × soybean hull interactions ($P > 0.37$ and $P > 0.17$, respectively) were observed; however, diet form × particle size interactions were observed for F/G and ADFI ($P < 0.05$ and $P < 0.10$, respectively). Grinding soybean hulls resulted in improved F/G and reduced ADFI when added to meal diets, but did not change F/G and had less effect on ADFI when added to pelleted diets. Diet form × particle size interactions ($P < 0.05$) also were observed for caloric efficiency on an ME and NE basis. Grinding soybean hulls slightly improved caloric efficiency in meal diets but worsened NE and ME caloric efficiency in pelleted diets. There was also a tendency for a diet form × soybean hulls interaction ($P < 0.06$) for ADFI and F/G. Increasing soybean hulls from 10 to 20% increased ADFI and worsened F/G in meal diets but resulted in slightly reduced ADFI and no changes to F/G when added to pelleted diets; furthermore, there were tendencies for diet form × soybean hulls interactions ($P < 0.06$) on caloric efficiency on an ME and NE basis in which increasing soybean hulls from 10 to 20% improved caloric efficiency to a greater extent in pelleted diets than in meal diets.

For main effects, pigs fed diets with 10% soybean hulls had reduced ($P < 0.007$) ADFI and improved ($P < 0.03$) F/G but poorer caloric efficiency ($P < 0.001$) on an ME and NE basis than pigs fed diets with 20% soybean hulls. Grinding soybean hulls decreased ($P < 0.005$) ADG and ADFI and tended ($P < 0.08$) to reduce final weight but did not influence F/G. Pelleting soybean hull diets also increased ($P < 0.0001$) ADG, ADFI, and final weight but did not influence F/G. In summary, the improvement in caloric efficiency as high levels of soybean hulls were added to the diet indicate that the energy value of soybean hulls are greater than those used in diet formulation. Pelleting

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[2] Appreciation is expressed to Kalmbach Feeds, Inc. for use of pigs and facilities and to Dr. Casey Bradley and Lorene Parkhurst for technical support.

[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[4] Kalmbach Feeds, Inc., Upper Sandusky, OH.

provided the expected improvement in ADG and eliminated the negative effect on F/G with increasing soybean hulls. Regrinding soybean hulls below the particle size at receiving (617 μ) reduced performance.

Key words: nursery pig, particle size, soybean hulls

Introduction

Soybean hulls are a readily available co-product from the cracking and dehulling process of soybean oil extraction, but because of soybean hulls' low energy value (corn NE = 1,202 kcal/lb; soybean hulls NE = 455 kcal/lb; INRA 2004[5]) and the lack of published data, soybean hulls may be an underutilized ingredient in many swine diets. Previous studies at Kansas State University have shown that up to 5% soybean hulls can be added to nursery pig diets without affecting growth performance (see Goehring et al., "The Effects of Soybean Hulls on Nursery Pig Growth Performance" p. 127). These results suggest that the ME value of soybean hulls might be underestimated when fed at low inclusions in swine diets.

Soybean hulls from U.S. processing plants vary in particle size, but a recent study by Moreira et al. (2009[6]) showed that reducing the particle size of soybean hulls from 751 μ to 439 μ, increased the ME value for finishing pigs and improved growth performance. Validation of the response to grinding soybean hulls on growth performance is needed; in addition, because soybean hulls have a low bulk density, research on the effects of pelleting complete diets containing high amounts of soybean hulls is needed.

Therefore, the objectives of this study were to evaluate the effects of (1) soybean hulls (10 and 20%), (2) soybean hull particle size (617 vs. 398 μ), and (3) diet form (meal and pellet) on the growth performance of nursery pigs in a commercial setting.

Procedures

The protocol for this experiment was approved by the K-State Institutional Animal Care and Use Committee. The study was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc.

A total of 1,100 pigs (PIC C-29 x 359, initially 15.0 lb BW) were used in a 42-d growth trial. Pens of pigs (5 barrows and 5 gilts per pen) were balanced by initial BW and randomly allotted to treatments with 11 replications (pens) per treatment. Each pen had slatted metal floors and was equipped with a 4-hole stainless steel feeder and one nipple-cup waterer for ad libitum access to feed and water.

Pigs were weaned and started on a common pelleted starter diet for 10 d prior to the initiation of the experiment. A 2-phase diet series was used with treatment diets fed

[5] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez, and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

[6] Moreira, I., M. Kutschenko, D. Paiano, C. Scapinelo, A. E. Murakami, and A. R. Bonet de Quadros. 2009. Effects of different grinding levels (particle size) of soybean hull on starting pigs performance and digestibility. Braz. Arch. Biol. Technol. 52(5):1243–1252.

from d 0 to 14 for Phase 1 and d 14 to 42 for Phase 2 arranged in a 2 × 2 × 2 factorial. The dietary treatments were corn-soybean–based diets containing 10 or 20% unground or finely ground soybean hulls in pelleted and meal form (Table 1). Phase 1 diets contained 4% fish meal and 10% spray-dried whey. Phase 2 diets contained no specialty protein sources. Pig weight and feed disappearance were measured on d 0, 7, 14, 21, 28, 35, and 42 to determine ADG, ADFI, and F/G.

A single lot of soybean hulls were used for the study with 50% used as received, whereas the other 50% was ground through a hammer mill equipped with a 1/16-in. screen at K-State Grain Science Feed Mill. The resulting particle sizes were 617 and 398 μ, respectively. All soybean hulls were then shipped to Kalmbach Feeds, Inc. for feed manufacturing. Samples of soybean hulls and complete diet were collected for chemical analysis. Proximate analysis was conducted by Ward Laboratories, Inc. (Kearny, NE) on the soybean hulls (Table 2). All diets were formulated to the same standardize ileal digestible (SID) lysine level. Feed samples were collected from each feeder during each phase and combined for a single composite sample of each treatment per phase. The pellet durability index (PDI) and percentage fines were determined for pelleted diets (Table 3), and bulk densities were determined for all diets (Table 4).

Data was analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Room was included in the model as a random effect and contrasts were used to test for the following interactions: (1) form × soybean hulls × soybean hull particle size, (2) form × soybean hull particle size, (3) form × soybean hulls, and (4) soybean hulls × soybean hull particle size. Main effects of diet form, soybean hulls, and soybean hull particle size were also tested. Differences between treatments were determined by using least squares means ($P < 0.05$), and trends were declared at $P < 0.10$.

Results and Discussion

Unground soybean hulls had a lower bulk density than ground soybean hulls, and diets containing 20% soybean hulls had lower bulk densities and increased particle sizes than diets with 10% soybean hulls. Soybean hulls did not affect pellet durability, regardless of the amount of soybean hulls or particle size, but diets with 20% soybean hulls had decreased percentage fines.

From d 0 to 14, no interactions ($P > 0.23$) were observed. Increasing dietary soybean hulls from 10 to 20% improved ($P < 0.003$) ADG, F/G, and caloric efficiency on an ME and NE basis (Table 5). Grinding soybean hulls worsened ($P < 0.003$) ADG, F/G, and caloric efficiency, whereas pelleted soybean hull diets increased ($P < 0.001$) ADG and ADFI but did not affect F/G or caloric efficiency.

From d 14 to 42, tendencies were observed for diet form × soybean hull particle size and diet form × soybean hulls interactions ($P < 0.10$) in which grinding soybean hulls reduced ADFI in meal diets but had less of an effect on ADFI in pelleted diets. Similarly, increasing soybean hulls from 10 to 20% increased ADFI and worsened F/G in meal diets but had no effect on F/G and slight increases in ADFI in pelleted diets. Additionally, there were tendencies for diet form × soybean hulls interactions ($P < 0.10$) on ME and NE caloric efficiencies in which 20% soybean hulls improved caloric efficiency to a greater extent in pelleted diets than in meal diets. For main effects, increasing soybean hulls from 10 to 20% increased ($P < 0.002$) ADFI and worsened ($P < 0.001$) F/G but had no effect on ADG. Increasing soybean hulls also improved ($P < 0.04$) caloric efficiency on an ME and NE basis, indicating the energy value of soybean hulls was underestimated in diet formulation. Grinding soybean hulls tended ($P < 0.06$) to decrease ADG and decreased ($P < 0.001$) ADFI without influencing F/G or caloric efficiency. Pelleting the diets also increased ($P < 0.001$) ADG and ADFI but had no effect on F/G or caloric efficiency.

Overall (d 0 to 42), there were no soybean hull level × particle size × diet form or particle size × soybean hull level interactions ($P > 0.37$ and $P > 0.17$, respectively); however, diet form × particle size interactions occurred for F/G and ADFI ($P < 0.05$ and $P < 0.10$, respectively) in which grinding the soybean hulls improved F/G and reduced ADFI when added to meal diets but did not change F/G and had less effect on ADFI when added to pelleted diets. Additionally, diet form × particle size interactions ($P < 0.05$) were observed for caloric efficiency on an ME and NE basis. Grinding soybean hulls slightly improved caloric efficiency in meal diets, but worsened NE and ME caloric efficiency in pelleted diets. A tendency for a diet form × soybean hulls level interactions ($P < 0.06$) was observed for ADFI and F/G in which increasing soybean hulls from 10 to 20% increased ADFI and worsened F/G in meal diets but resulted in slightly reduced ADFI and no changes to F/G in pelleted diets. Increasing the amount of soybean hulls reduced the dietary energy content of the diet. To meet the energy requirement, ADFI increased, but with no change in pigs' ADG, the result was poorer F/G. Furthermore, tendencies for diet form × soybean hulls level interactions ($P < 0.06$) were observed for caloric efficiency on an ME and NE basis. Increasing soybean hulls from 10 to 20% improved caloric efficiency to a greater extent in pelleted diets than in meal diets. The increase in soybean hulls reduced the calculated energy concentration in the diet to a greater extent than F/G increased. Pelleting the diets containing high levels of soybean hulls may have improved digestibility and resulted in a greater improvement in caloric efficiencies.

For main effects, increasing soybean hulls from 10 to 20% increased ($P < 0.007$) ADFI but worsened ($P < 0.03$) F/G (Table 6). Dietary energy decreased with 20% soybean hulls in the diet, and ADFI increased to compensate for the lower energy diet. Because ADG was unchanged despite soybean hull inclusions, pigs gained the same amount on lower energy diets, resulting in improved ($P < 0.001$) caloric efficiency on an ME and NE basis. This suggests that the energy value for soybean hulls is overestimated. Grinding soybean hulls reduced ($P < 0.005$) ADG and ADFI, whereas pelleted diets improved ($P < 0.001$) ADG and ADFI, but pelleting the diets and grinding the soybean hulls did not affect F/G or caloric efficiency. Grinding the soybean hulls tended ($P < 0.08$) to reduce final pig weight. Feeding pelleted diets increased ($P < 0.001$) final weight.

In conclusion, soybean hulls are a low-energy ingredient that increased crude fiber and NDF of the diet and worsened F/G when fed at 20% compared with 10%; however, pelleting these diets resulted in little change in F/G compared with the 20% inclusion fed in meal form. Pigs fed 20% soybean hulls also had improved caloric efficiency coupled with reduced F/G, which suggests that the published energy value for soybean hulls may underestimate the value in diets containing 20% or less soybean hulls. Pelleting diets not only gave the typical improvement in ADG, but also increased feed intake, which results in no improvement in feed efficiency compared with pigs fed a meal diet. Pelleting diets would normally be expected to improve F/G without altering ADFI, but the improved feed intake could be the result of providing a more dense feed, because soybean hulls in a meal diets reduced diet bulk density. The hypothesis that reducing the particle size of soybean hulls may improve its energy value was not proven true, because feed efficiency and caloric efficiency were not influenced by soybean hull particle size. Grinding soybean hulls finer than (617 μ) actually reduced feed intake and ADG.

Table 1. Phase 1 and Phase 2 diet composition (as-fed basis)[1,2,3]

	Phase 1		Phase 2	
Item Soybean hulls, %:	10%	20%	10%	20%
Ingredient, %				
Corn	46.15	37.06	55.07	45.91
Soybean meal, 46.5% CP	26.83	26.06	31.33	30.64
Soybean hulls	10.00	20.00	10.00	20.00
Select menhaden fish meal	4.00	4.00	--	--
Spray-dried whey	10.00	10.00	--	--
Monocalcium P, 21% P	0.50	0.50	1.05	1.05
Limestone	0.65	0.50	0.80	0.65
Salt	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	--	--
Vitamin E (20,000 IU)	0.055	0.055	0.055	0.055
Vitamin premix	0.05	0.05	0.05	0.05
Trace mineral premix	0.09	0.09	0.09	0.09
Se 600 premix	0.023	0.023	0.023	0.023
L-lysine HCl	0.213	0.200	0.315	0.300
DL-methionine	0.140	0.158	0.148	0.165
L-threonine	0.115	0.120	0.130	0.135
Ronozyme CT (10,000)[4]	0.019	0.019	0.019	0.019
CTC 50	0.40	0.40	0.40	0.40
Denagard 10	0.175	0.175	0.175	0.175
Total	100	100	100	100

continued

Table 1. Phase 1 and Phase 2 diet composition (as-fed basis)[1,2,3]

		Phase 1		Phase 2	
Item	Soybean hulls, %:	10%	20%	10%	20%
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine		1.30	1.30	1.26	1.26
Isoleucine:lysine		62	62	61	61
Leucine:lysine		125	122	126	123
Methionine:lysine		36	36	34	35
Met & Cys:lysine		59	59	58	58
Threonine:lysine		64	64	63	63
Tryptophan:lysine		17.5	17.5	17.5	17.5
Valine:lysine		68	67	67	66
Total lysine, %		1.46	1.48	1.42	1.44
ME, kcal/lb		1,427	1,359	1,431	1,363
SID lysine:ME, g/Mcal		4.20	4.48	4.05	4.33
CP, %		21.7	21.8	21.0	21.1
Crude fiber, %		5.4	8.5	5.8	8.9
ADF[5]		6.8	10.6	7.3	11.0
NDF[6]		12.5	17.2	13.7	18.4
Ca, %		0.78	0.77	0.67	0.66
P, %		0.63	0.61	0.61	0.59
Available P, %		0.46	0.46	0.40	0.40

[1] Phase 1 diets fed from d 0 to 14; Phase 2 diets fed from d 14 to 42.
[2] Diets were fed in both meal and pelleted forms.
[3] Diets were fed with soybean hulls ground to 389 µ or unground at 617 µ
[4] Ronozyme CT (10,000) (DSM, Parsippany, NJ) provided 840 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Soybean hulls ADF values taken from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.
[6] Soybean hulls NDF values taken from INRA, 2004. All other values taken from NRC, 1998.

Table 2. Chemical analysis of soybean hulls (as-fed basis)

Item	Percentage	
DM	91.91	
CP	9.8 (12.2)[1]	
ADF	40.1	
NDF	55.3	
Crude fiber	32.7 (33.3)	
Ca	0.54 (0.52)	
P	0.11 (0.15)	
	Ground	Unground
Bulk density, lb/bu[2]	38.09	32.74
Particle size, μ	389	617

[1] Values in parentheses were used in diet formulation.
[2] Diet samples taken from the top of each feeder in each phase.

Table 3. Quality of pelleted diets

Grind type:	Unground		Ground	
Item Soybean hull level, %:	10%	20%	10%	20%
Phase 1				
PDI, %[1]	95	95	94	95
Modified PDI, %	93	92	89	92
Fines, %	7.6	0.5	6.6	3.6
Phase 2				
PDI, %	97	97	95	94
Modified PDI, %	94	95	92	92
Fines, %	6.1	1.5	1.8	0.8

[1] PDI: pellet durability index; samples were taken from each feeder during each phase. A composite sample was made for each treatment.

Table 4. Bulk density of experimental diets (as-fed basis)[1,2]

	Treatments							
Diet form:	Meal				Pellet			
Grind type:	Unground		Ground		Unground		Ground	
Item Soybean hulls, %:	10%	20%	10%	20%	10%	20%	10%	20%
Bulk density, lb/bu								
Phase 1	47.9	44.7	48.5	46.6	59.6	55.7	57.5	56.9
Phase 2	54.3	49.1	54.5	50.2	60.0	58.5	60.0	60.1
Particle size, µ								
Phase 1	355	400	360	364	--	--	--	--
Phase 2	430	558	423	500	--	--	--	--

[1] Diet samples collected from the tops of each feeder during each phase.
[2] Phase 1 was d 0 to 14; Phase 2 was d 14 to 42.

Table 5. Interactions of soybean hulls level, particle size and complete diet form on nursery pig performance[1]

Diet form:	Meal				Pellet						
Grind type:	Unground		Ground		Unground		Ground				
Item Soybean hulls, %:	10%	20%	10%	20%	10%	20%	10%	20%	SEM[2,3]	Diet form × soybean hulls particle size	Diet form × soybean hulls
d 0 to 14											
ADG, lb	0.35	0.40	0.33	0.37	0.45	0.45	0.39	0.43	0.061	0.35	0.33
ADFI, lb	0.61	0.65	0.60	0.62	0.74	0.70	0.72	0.74	0.061	0.45	0.19
F/G	1.79	1.64	1.90	1.73	1.70	1.55	1.95	1.75	0.142	0.21	0.88
Caloric efficiency[4]											
ME	2,550	2,227	2,705	2,349	2,421	2,109	2,783	2,378	198.8	0.23	0.90
NE	1,822	1,555	1,934	1,1641	1,730	1,472	1,989	1,661	141.0	0.23	0.90
d 14 to 42											
ADG, lb	1.40	1.38	1.35	1.36	1.44	1.41	1.40	1.41	0.032	0.86	0.96
ADFI, lb	2.04	2.12	1.94	2.04	2.10	2.09	2.03	2.09	0.068	0.10	0.07
F/G	1.46	1.53	1.43	1.49	1.46	1.48	1.46	1.49	0.026	0.19	0.09
Caloric efficiency											
ME	2,085	2,088	2,052	2,034	2,091	2,020	2,095	2,027	36.0	0.19	0.10
NE	1,459	1,425	1,435	1,388	1,463	1,379	1,466	1,383	24.8	0.19	0.10
d 0 to 42											
ADG, lb	1.05	1.05	1.01	1.03	1.11	1.09	1.05	1.08	0.039	0.91	0.79
ADFI, lb	1.56	1.62	1.49	1.56	1.65	1.61	1.59	1.64	0.064	0.10	0.06
F/G	1.49	1.54	1.47	1.52	1.49	1.49	1.51	1.52	0.016	0.05	0.06
Caloric efficiency											
ME	2,130	2,102	2,109	2,066	2,128	2,028	2,161	2,066	22.8	0.05	0.06
NE	1,494	1,439	1,479	1,414	1,493	1,389	1,517	1,415	15.8	0.05	0.06
BW, lb											
d 0	15.0	15.1	14.9	14.9	14.9	15.0	15.1	15.0	0.15	0.22	0.52
d 14	19.9	20.7	19.5	20.1	21.2	21.4	20.4	21.0	0.96	0.80	0.36
d 42	59.0	59.3	57.4	58.2	61.4	60.8	59.3	60.4	1.76	0.96	0.73

[1] A total of 1100 pigs (PIC C-29 × 359, initially 15.0 lb BW) were used in a 42-d study with 10 pigs per pen and 11 pens per treatment.
[2] No soybean hull × particle size × diet form interactions, $P > 0.37$.
[3] No particle size × soybean hull interaction, $P > 0.17$.
[4] Caloric efficiency is express as kcal/lb gain.

Table 6. Main effects of soybean hulls level, particle size, and complete diet from on nursery pig performance[1]

	Diet form		Soybean hulls particle size		Soybean hulls			Probability, *P*<		
Item	Meal	Pellet	Unground	Ground	10%	20%	SEM	Soybean hulls	Soybean hulls particle size	Diet form
d 0 to 14										
ADG, lb	0.36	0.43	0.41	0.38	0.38	0.41	0.060	0.003	0.003	0.0001
ADFI, lb	0.62	0.72	0.67	0.67	0.67	0.68	0.058	0.58	0.84	0.0001
F/G	1.76	1.74	1.67	1.83	1.83	1.67	0.128	0.002	0.002	0.63
Caloric efficiency[2]										
ME	2,458	2,422	2,326	2,554	2,615	2,265	178.1	0.0001	0.002	0.63
NE	1,738	1,713	1,645	1,806	1,869	1,582	126.2	0.0001	0.002	0.63
d 14 to 42										
ADG, lb	1.37	1.41	1.41	1.38	1.39	1.39	0.027	0.71	0.06	0.01
ADFI, lb	2.03	2.08	2.08	2.02	2.03	2.08	0.064	0.002	0.0008	0.008
F/G	1.48	1.47	1.48	1.47	1.45	1.50	0.020	0.001	0.31	0.70
Caloric efficiency										
ME	2,065	2,059	2,071	2,052	2,081	2,042	28.1	0.04	0.30	0.74
NE	1,427	1,423	1,431	1,418	1,456	1,394	19.4	0.0001	0.30	0.75
d 0 to 42										
ADG, lb	1.04	1.08	1.08	1.05	1.06	1.07	0.037	0.45	0.005	0.0001
ADFI, lb	1.56	1.63	1.61	1.57	1.57	1.61	0.02	0.007	0.004	0.0001
F/G	1.51	1.50	1.50	1.51	1.49	1.52	0.01	0.03	0.82	0.69
Caloric efficiency										
ME	2,102	2,096	2,097	2,101	2,132	2,266	11.4	0.0001	0.83	0.76
NE	1,457	1,453	1,454	1,456	1,496	1,414	7.9	0.0001	0.82	0.78
BW, lb										
d 0	15.0	15.0	15.0	15.0	15.0	15.0	0.10	0.83	0.87	0.71
d 14	20.0	21.0	20.8	20.3	20.3	20.8	0.94	0.002	0.002	0.0001
d 42	58.5	60.5	60.1	58.8	59.3	59.7	1.67	0.42	0.08	0.0001

[1] A total of 1,100 pigs (PIC C-29 × 359, initially 15.0 lb BW) were used in a 42-d study with 10 pigs per pen and 11 pens per treatment.

[2] Caloric efficiency is express as kcal/lb gain.

The Effects of Soybean Hulls and Their Particle Size on Growth Performance and Carcass Characteristics of Finishing Pigs[1]

D. L. Goehring, J. M. DeRouchey, S. S. Dritz[2], M. D. Tokach, R. D. Goodband, and J. L. Nelssen

Summary

A total of 1,235 pigs (PIC 337 × 1050; initially 68.4 lb) were used in a 118-d study to determine the effects of 7.5 and 15% ground or unground soybean hulls on growth performance and carcass characteristics of finishing pigs raised in a commercial environment. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 5 dietary treatments in a completely randomized design with 26 to 28 pigs per pen and 9 replications per treatment. Treatments were arranged in a 2 × 2 factorial, and main effects were soybean hull particle size (unground or ground, 787 and 370 μ, respectively) and amount of soybean hulls (7.5 or 15%) in corn-soybean meal–based diets. The fifth treatment was a positive control, a corn-soybean meal–based diet. No particle size × soybean hull interactions ($P > 0.18$) occurred. Overall (d 0 to 118), increasing soybean hulls, regardless of particle size, did not affect ADG but numerically increased ($P = 0.11$) ADFI, resulting in poorer (linear, $P < 0.02$) F/G. Although F/G became worse, increasing soybean hulls in the diet improved (linear, $P < 0.002$) caloric efficiency on an ME and NE basis, indicating that published energy values undervalue the energy content of soybean hulls. Unexpectedly, grinding soybean hulls to a lower particle size worsened F/G ($P < 0.04$) and caloric efficiencies ($P < 0.03$).

Because adding soybean hulls increases the dietary fiber content, pigs fed high amounts of soybean hulls would be expected to have greater gut fill, which is reflected by the lower (linear, $P < 0.03$) carcass yield and HCW for pigs fed increasing amounts of soybean hulls. Increasing soybean hulls decreased (linear, $P < 0.0006$) backfat depth. The reduction in backfat resulted in an increase ($P < 0.008$) in percentage lean and fat-free lean index (FFLI) with increasing soybean hulls. Grinding soybean hulls to a finer particle size prior to diet manufacturing increased backfat depth ($P < 0.002$) and decreased ($P < 0.004$) percent lean and FFLI.

In summary, increasing amounts of dietary soybean hulls to 7.5 or 15% did not affect ADG, ADFI, or final BW in growing and finishing pigs; however, F/G became poorer and carcass yield and HCW decreased. Thus, producers using soybean hulls in finishing diets may want to withdraw or reduce levels prior to market to decrease the negative impact on carcass yield. Further processing soybean hulls by grinding to a finer particle size provided no advantages in performance and actually worsened F/G.

Key words: finishing pig, particle size, soybean hulls

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[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Introduction

Soybean hulls are a readily available co-product resulting from the cracking and dehulling process in soybean oil extraction, but they may be underutilized in many swine diets because of their low energy value (corn NE = 1,202 kcal/lb; soybean hulls NE = 455 kcal/lb; INRA 2004[3]) and the lack of published data. Research at Purdue University (Bowers et al., 2000[4]) has shown that low amounts of soybean hulls (3%) improved finishing pig ADG, ADFI, and carcass characteristics, but higher amounts of soybean hulls reduced growth performance and worsened F/G.

Reducing particle size of cereal grains is well known to improve feed efficiency. In a recent study, Moreira et al. (2009[5]) found that grinding soybean hulls increased ME for finishing pigs when soybean hulls were ground from 751 µ to 430 µ, with potential improvements in growth performance. Validation of the benefits of grinding soybean hulls on growth performance is needed; therefore, the objectives of this study were to evaluate the effects of: (1) increasing amounts of soybean hulls (0, 7.5, and 15%), and (2) soybean hull particle size (787 vs. 370 µ) on the growth performance of growing and finishing pigs in a commercial setting.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

The study was conducted at the commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 1,235 pigs (PIC 1050 × 337) with an initial BW of 68.4 lb were used in a 118-d study. A similar number of barrows and gilts were placed in each pen, with 26 to 28 pigs per pen and 9 pens per treatment. Pens of pigs were allotted to 1 of 5 dietary treatments in a completely randomized design while balancing for BW. Treatments were arranged as a 2 × 2 + 1 factorial with main effects of soybean hull (unground or ground, 787 and 370 µ, respectively) and soybean hull inclusion (7.5 or 15%). The fifth treatment was a positive control, a corn-soybean meal–based diet without soybean hulls.

All soybean hulls were sourced from the same location (South Dakota Soybean Processors, Volga, SD). Each lot of soybean hulls was split into equal portions, and half was transported to the South Dakota State University Feed Mill (Brookings, SD) then

[3] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

[4] Bowers et al., Purdue University Swine Day 2000, pp. 39–42.

[5] Moreira, I., M. Kutschenko, D. Paiano, C. Scapinelo, A. E. Murakami, and A. R. Bonet de Quadros. 2009. Effects of different grinding levels (particle size) of soybean hull on starting pigs performance and digestibility. Braz. Arch. Biol. Technol. v.52 n.5:1243–1252.

ground through a 1/16-in. screen. After grinding, hulls were transported along with the unground soybean hulls to the New Horizon Farm's feed mill (Pipestone, MN) for diet manufacturing. All diets were fed in meal form and treatments were fed in 4 phases, from 70 to 120 lb, 120 to 170 lb, 170 to 240 lb, and 240 lb to market. Diets in the last phase also contained 9 g/ton of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).

Pens of pigs were weighed and feed disappearance was recorded at d 14, 28, 42, 53, 66, 82, 94, and 118 to determine ADG, ADFI, and F/G. On d 94 of the experiment, the 4 heaviest pigs (2 barrows and 2 gilts, determined visually) per pen were weighed and sold according to the farm's normal marketing procedure. At the end of the trial (d 118), pigs were individually tattooed by pen number to allow for carcass data collection. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Hot carcass weights were measured immediately after evisceration and standard carcass criteria of percentage yield, HCW, percentage lean, backfat depth, and loin depth were collected. Percentage carcass yield was calculated by dividing live weight at the plant with carcass weight at the plant as reported by the processor. The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data. Interactions between particle size and dietary soybean hull levels were analyzed, as well as the main effects of particle size and the linear and quadratic effects of increasing soybean hulls, regardless of particle size. Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

The analyzed nutrient levels of the soybean hulls used in the experiment were similar to those used in diet formulation (Table 1). In addition, reducing the particle size of soybean hulls improved bulk density compare to the unground soybean hulls. Adding increasing amounts of soybean hulls to the diets increased crude fiber (CF; from 2.6 to 7.2%) and NDF (from 9.2 to 16.3).

Despite these increases in dietary CF and NDF (Table 2) with added soybean hulls, no negative effects were observed on ADG, ADFI, or final live BW (Table 3); however, increasing dietary soybean hulls decreased ME and NE energy of the diet and resulted in the worsening of F/G ($P < 0.02$). Caloric efficiency improved ($P < 0.002$) on an ME and NE basis as soybean hulls were added, indicating that the energy values of soybean hulls were underestimated in diet formulation. Unexpectedly, grinding the soybean hulls did not influence ADG or ADFI, but the numerical changes in these criteria resulted in poorer ($P < 0.04$) F/G and caloric efficiency on an ME and NE basis.

For carcass characteristics, increasing soybean hulls, regardless of soybean hull particle size, reduced (linear, $P < 0.03$) carcass yield and HCW. Backfat depth also was reduced (linear, $P < 0.0006$) when soybean hulls were added to the diet. Because of the reduction in backfat depth, percent lean and FFLI increased (linear, $P < 0.003$) as soybean hull level increased in the diet. Reducing the particle size of soybean hulls reduced ($P < 0.002$) backfat depth, resulting in an increase ($P < 0.004$) in percentage lean and FFLI.

In summary, based on data from this study, soybean hulls can be used in finishing pig diets up to 15% without negative effects on ADG, ADFI, or live pig weights; as expected, feed efficiency worsens with the addition of soybean hulls due to a decrease in dietary energy, but the improvement in caloric efficiency indicates that the energy value of soybean hulls is underestimated by published values when used at lower levels in the diet. Soybean hulls increase dietary CF and NDF, which can lead to greater gut fill and an increase in digestive tract tissue weights, thus causing a reduction in carcass yield and HCW. The worsening of feed efficiency for pigs fed soybean hulls with reduced particle size was unexpected, and why this occurred is unclear. These data suggest that soybean hulls do not respond similarly to cereal grains when fed at a reduced particle size in growing and finishing pig diets.

Table 1. Chemical analysis of soybean hulls (as-fed basis)[1]

Item	Percentage	
DM	91.51	
CP	10.61 (9.80)[2]	
ADF	43.6	
NDF	55.9	
Crude Fiber	36.3 (33.3)	
Ca	0.58 (0.54)	
P	0.11 (0.11)	
	Ground	Unground
Bulk density, lb/bu	41.26	36.34
Particle size, μ	370	787

[1] Samples of every batch of soybean hulls used were analyzed and averages are reported.

[2] Values in parentheses indicate those used in diet formulation.

Table 2. Diet composition (as-fed basis)[1]

	Phase 1			Phase 2			Phase 3			Phase 4		
Item Soybean hulls, %:[2]	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15
Ingredient												
Corn	73.09	66.09	58.98	78.78	71.61	64.63	83.01	75.84	64.63	75.24	68.03	60.94
Soybean meal, 46.5% CP	24.44	24.02	23.71	18.96	18.75	18.33	14.89	14.67	18.33	22.62	22.41	22.09
Soybean hulls	-	7.50	15.00	-	7.50	15.00	-	7.50	15.00	-	7.50	15.00
Monocalcium P, 21% P	0.62	0.63	0.65	0.51	0.50	0.48	0.40	0.40	0.40	0.25	0.28	0.28
Limestone	0.95	0.85	0.75	0.95	0.85	0.75	0.93	0.83	0.73	0.90	0.80	0.70
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-methionine	0.03	0.045	0.06	-	0.015	0.030	-	0.005	0.010	0.050	0.060	0.075
L-threonine	0.045	0.05	0.0525	0.015	0.019	0.030	0.03	0.035	0.040	0.070	0.075	0.080
Biolys[3]	0.370	0.360	0.345	0.325	0.305	0.295	0.030	0.035	0.040	0.008	0.008	0.008
Phytase[4]	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.000	0.008
Paylean, 9 g/lb	-	-	-	-	-	-	-	-	-	0.05	0.05	0.05
Total	100	100	100	100	100	100	100	100	100	100	100	100

continued

Table 2. Diet composition (as-fed basis)[1]

	Phase 1			Phase 2			Phase 3			Phase 4		
Item Soybean hulls, %:[2]	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15
Calculated analysis												
Standardized ileal digestible (SID) amino acids,%												
Lysine	1.00	1.00	1.00	0.84	0.84	0.84	0.72	0.72	0.72	0.95	0.95	0.95
Isoleucine:lysine	65	64	64	66	66	66	68	68	67	65	65	65
Leucine:lysine	146	143	140	159	156	152	173	168	164	150	147	143
Methionine:lysine	29	30	31	28	29	30	30	30	30	32	32	33
Met & Cys:lysine	57	57	57	58	58	58	63	61	60	60	60	60
Threonine:lysine	61	61	61	61	61	61	65	65	65	65	65	65
Tryptophan:lysine	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Valine:lysine	74	73	72	77	76	75	81	79	78	75	74	73
Total lysine, %	1.12	1.13	1.14	0.94	0.96	0.97	0.81	0.83	0.84	1.06	1.08	1.09
ME, kcal/lb	1,517	1,450	1,382	1,519	1,452	1,385	1,522	1,455	1,387	1,523	1,455	1,388
SID lysine:ME, g/Mcal	2.99	3.13	3.28	2.51	2.62	2.75	2.15	2.25	2.35	2.83	2.96	3.10
CP, %	17.9	17.9	17.8	15.8	15.8	15.7	14.2	14.2	14.2	17.3	17.3	17.3
Crude fiber, %	2.6	4.9	7.2	2.5	4.8	7.1	2.4	4.7	7.1	2.5	4.9	7.2
ADF[5]	3.4	6.2	9.0	3.2	6.1	8.9	3.1	6.0	8.8	3.3	6.2	9.0
NDF[5]	9.2	12.7	16.2	9.3	12.8	16.3	9.3	12.8	16.3	9.2	12.8	16.3
Ca, %	0.58	0.58	0.58	0.54	0.54	0.54	0.50	0.50	0.50	0.49	0.49	0.49
P, %	0.50	0.49	0.48	0.46	0.44	0.42	0.42	0.41	0.39	0.42	0.41	0.40
Available P, %	0.29	0.29	0.29	0.25	0.25	0.25	0.23	0.23	0.23	0.21	0.21	0.21

[1] Phase 1 diets fed from d 0 to 14, Phase 2 from d 14 to 53, Phase 3 from d 53 to 94, and Phase 4 from d 94 to 118.
[2] In diets containing soybean hulls, the soybean hulls were either unground at 787 μ or ground to 370 μ.
[3] Lysine source (Evonik Inc., Kennesaw, GA).
[4] Optiphos 2000 (Enzyva LLC, Sheridan, IN), providing 170.25 phytase units (FTU)/lb, with a release of 0.10% available P.
[5] Soybean hulls ADF and NDF values are from INRA (Institut National de la Recherche Agronomique), 2004. All other values taken from NRC, 1998.

Table 3. Effects of ground and unground soy hulls on growth performance and carcass characteristics[1]

							Probability, P<			
Soybean hulls, %:	0	7.5		15			Soybean hull	Soybean hulls	Soybean hulls	
Item / Particle size:	-	Ground	Unground	Ground	Unground	SEM[2]	particle size	level	Linear	Quadratic
d 0 to 118										
ADG, lb	1.84	1.85	1.85	1.81	1.86	0.022	0.34	0.45	0.78	0.53
ADFI, lb	4.69	4.86	4.73	4.79	4.80	0.054	0.31	0.96	0.11	0.31
F/G	2.56	2.63	2.58	2.67	2.60	0.026	0.04	0.26	0.02	0.75
Caloric efficency[3]										
ME	3,874	3,853	3,772	3,760	3,664	39.2	0.03	0.01	0.002	0.60
NE	2,869	2,810	2,752	2,700	2,632	28.6	0.03	0.0002	0.0001	0.61
BW, lb										
d 0	68.3	68.4	68.3	68.4	68.4	1.75	0.99	0.97	0.96	0.99
d 118	282.2	283.5	280.9	278.2	283.6	3.06	0.64	0.68	0.73	0.83
Carcass characteristics										
Plant carcass yield, %	76.26	75.23	75.42	75.16	74.96	0.361	0.55	0.12	0.001	0.13
HCW	208.3	206.9	204.4	201.9	202.1	2.32	0.62	0.13	0.03	0.83
Backfat depth, in.	0.61	0.59	0.56	0.58	0.54	0.010	0.002	0.13	0.0006	0.38
Loin depth, in.	2.62	2.56	2.60	2.61	2.57	0.026	0.84	0.67	0.32	0.25
Lean, %	57.44	57.54	58.06	57.82	58.39	0.186	0.004	0.12	0.008	0.89
FFLI[4]	54.12	54.28	54.75	54.50	55.07	0.168	0.003	0.13	0.003	0.63

[1] A total of 1,235 pigs (PIC 337 x 1050; initially 68.4 lb) were used in a 118-d study with 9 replications per treatment.
[2] No soybean hull particle size × soybean hull level interactions P > 0.18.
[3] Caloric efficiency is expressed as kcal/lb gain.
[4] Fat-free lean index was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + HCW, lb) – (31.277 × last-rib fat thickness, in.) + (3.813 × loin muscle depth, in))/HCW, lb.

Effects of Increasing Dietary Bakery By-Product on Growing-Finishing Pig Growth Performance and Carcass Quality[1]

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Summary

A total of 1,263 pigs (PIC 337 × 1050; initially 77.8 lb) were used in a 102-d study to determine the effects of dietary bakery by-product on pig growth performance and carcass quality. Pigs were randomly assigned to pens based on gender (14 barrow pens, 11 gilt pens, and 23 mixed-gender pens). Pens of pigs were allotted to 1 of 3 dietary treatments in a completely randomized design while balancing for initial BW and gender. Dietary treatments included 0, 7.5, and 15% bakery by-product. On d 84, the 5 heaviest pigs from each pen (determined visually) were sold according to the normal marketing procedure of the farm. On d 102, the remaining pigs were individually tattooed by pen number and sent to harvest to allow for collection of carcass data. On d 84 and d 102, the median weight market pig from every pen was selected (determined visually) for collection of carcass quality measurements.

Overall (d 0 to 102), increasing bakery by-product worsened (linear, $P < 0.02$) F/G and caloric efficiency on a ME basis and pigs fed diets containing 7.5% bakery by-product tended to have the lowest (quadratic, $P < 0.07$) ADG. For pigs marketed on d 102, no differences ($P > 0.21$) were observed in carcass characteristics. For pigs subsampled on d 84, loin color score increased (linear; $P < 0.02$) and belly fat iodine value (IV) increased numerically (linear, $P < 0.09$) as the amount of bakery by-product increased. Pigs subsampled on d 102 had decreased (linear, $P < 0.04$) middle and edge belly thickness, increased (linear, $P < 0.001$; quadratic, $P < 0.07$) IV, and numerically lower (linear, $P < 0.09$) kill floor pH and belly weight as the amount of dietary bakery by-product increased. Pigs fed 15% bakery by-product had the lowest (quadratic, $P < 0.05$) belly temperature and belly firmness score. With the exception of belly fat IV, bakery by-products had few negative effects on carcass quality.

The negative effects of bakery by-product on feed efficiency, caloric efficiency on an ME basis, and belly fat IV should be taken into consideration when using bakery by-product in diet formulation.

Key words: bakery by-product, carcass quality, finishing pig

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

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Introduction

With the continuous increase in corn prices, swine producers are utilizing alternative feed ingredients to reduce diet cost. One option for producers to consider is a by-product of the baking and cereal industries. Bakery by-products have been reported to have higher dietary energy (corn ME = 1,551 kcal/lb; bakery by-product ME = 1,678 kcal/lb), CP (corn CP = 8.3%; bakery by-product CP = 10.8%), and fat (corn fat = 3.9%; bakery by-product = 11.3%; NRC, 1998[4]) than corn. Although bakery by-product can be a valuable energy source, its high levels of fat can have negative effects on carcass quality, and the nutrient values can vary greatly depending on the source of the bakery by-product and source and level of other ingredients added to improve flowability. The objective of this experiment was to determine the effects of increasing dietary bakery by-product on growth performance and carcass quality of growing-finishing pigs.

Procedures

This study was approved by and conducted in accordance with the guidelines of the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted in a commercial research finishing barn in Southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 1,263 pigs (PIC 337 × 1050; initially 77.8 lb) were used in a 102-d study. Pigs were randomly assigned to pens based on gender (14 barrow pens, 11 gilt pens, and 23 mixed-gender pens), with 25 to 28 pigs per pen. Pens of pigs were allotted to 1 of 3 dietary treatments in a completely randomized design while balancing for initial BW and gender. There were 16 pens per treatment. Treatments included 0, 7.5, and 15% bakery by-product in place of corn and soybean meal. Diets were not balanced for energy; thus, as bakery by-product increased, the energy content of the diet increased. Dietary treatments were fed in 5 phases, with phases from 78 to 137 lb, 137 to 175 lb, 175 to 203 lb, 203 to 225 lb, and 225 to 283 lb BW (Tables 1 and 2). In the last phase, 5 ppm of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) was added to the diet, and half of the pens from each of the bakery treatments were assigned to diets with and without zinc oxide (ZnO) so average weight was similar for the ZnO treatments within bakery by-product treatment. The main effects of the addition of Zn to diets containing Ractopamine HCl are reported in another report (see Paulk et al., "Effects of Added Zn in Diets with Ractopamine HCl on Growth Performance and Carcass Quality of Finishing Pigs in a Commercial Environment," p. 356).

Bakery by-product samples were collected at the time of feed manufacturing, and 3 composite samples were submitted for proximate analysis (Ward laboratories, Inc., Kearney, NE; Table 3). Feed samples were also collected from each feeder during each phase and combined for a single composite sample for each treatment in each phase to be analyzed for proximate analysis (Ward laboratories, Inc., Kearney, NE; Table 4).

[4] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

Pigs and feeders were weighed on d 0, 14, 30, 50, 64, 75, 84, 91, and 102 to determine ADG, ADFI, F/G, and caloric efficiency on both an ME and NE basis. Caloric efficiency is a method to measure the efficiency of energy usage, or the ME or NE required per pound of gain. Metabolizable energy values of the feed ingredients and the NE value of bakery by-product were derived from NRC (1998). Net energy values of all feed ingredients except bakery by-product were derived from INRA (2004[5]). On d 84, the 5 heaviest pigs from each pen (determined visually) were sold according to the normal marketing procedure of the farm. The median weight pig from the 5 selected pigs was tattooed by pen and used for collection of carcass quality measurements (live weight at the plant, HCW, backfat thickness, lean percentage, loin depth, kill floor pH, 4-h pH, belly temperature, belly weight, middle belly thickness, edge belly thickness, belly firmness, belly fat iodine value (IV), loin pH, loin color, and marbling. Percentage lean was calculated by dividing the standardized fat-free lean (SFFL) by HCW. The following equation was used for calculation of SFFL (NPPC, 2001[6]):

Lb. SFFL = 15.31 + 0.51 × (HCW, lb)-31.277 × (last-rib backfat thickness, in.) + 3.813 × (loin muscle depth, in.)

Belly firmness was determined using a subjective measurement taken by picking the belly up at mid-point and estimating the amount of bend. The firmness scale was 1 = none to very little bend, 2 = moderate or 50% bend, and 3 = belly ends touched. Loin color and marbling were taken on the exposed lean of the boneless loin (NPPC, 1999[7]). The loin color scale was from 1 to 6, with 1 = pale and 6 = dark. The marbling scores correspond to intramuscular lipid content, with 1 = very little to no intramuscular lipid content and 10 = extreme amounts.

On d 102, the remaining pigs were individually tattooed by pen number and sent to harvest to allow for collection of carcass data, including HCW, percentage yield at the farm and packing plant, backfat thickness, loin depth, and percentage lean. The median weight pig from each pen was selected for carcass quality measurements. The selection of either a barrow or gilt from mixed-sex pens was balanced across treatments for determination of carcass quality.

Data were analyzed using the PROC MIXED procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In addition to dietary treatment, the effects of gender (barrow, gilt, or mixed gender) were included as a fixed effect. Added Zn and interaction effects of increasing dietary bakery by-product and added Zn were tested for d 75 to 102 and carcass measurements. The interaction effect was not significant; therefore, it was removed from the model. The effects of increasing dietary bakery by-product level on performance criteria were determined by linear and quadratic polynomial contrasts. Hot carcass weight was used as a covariate for analyses of backfat

[5] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

[6] NPPC 2001. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Counc., Des Moines, IA.

[7] NPPC 1999. Composition and Quality Assessment Procedures. Natl. Pork Prod. Counc., Des Moines, IA

thickness, loin depth, and lean percentage. Statistical significance was claimed at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

The chemical analysis of the bakery by-product (Table 3) revealed that CP levels were higher and fat levels were lower than the formulated values.

From d 0 to 75, pigs fed 7.5% bakery by-product had decreased (quadratic, $P < 0.02$; Table 5) ADG. Pigs fed diets with up to 15% dietary bakery by-product had numerically poorer (linear, $P < 0.07$) F/G and had poorer (linear, $P < 0.01$) caloric efficiency on a ME basis.

From d 75 to 102, no differences were observed in ADG and ADFI (P > 0.17) as bakery by-product increased; however, F/G and caloric efficiency on a ME basis were poorer (linear, $P < 0.03$) as bakery by-product increased.

Overall (d 0 to 102), as dietary bakery by-product increased, F/G and caloric efficiency on a ME basis became poorer (linear, $P < 0.02$), and pigs fed diets with 7.5% bakery by-product tended to have the lowest (quadratic, $P < 0.07$) ADG. No differences ($P > 0.21$) were observed in carcass characteristics of pigs harvested on d 102.

For carcass quality measurements, pigs subsampled on d 84 had increased (linear; $P < 0.02$) loin color score and numerically increased (linear, $P < 0.09$) belly fat IV as the amount of dietary bakery by-product increased (Table 6). Pigs subsampled on d 102 had decreased (linear, $P < 0.04$) middle and edge belly thickness, increased (linear, $P < 0.001$; quadratic, $P < 0.07$) IV, and numerically lower (linear, $P < 0.09$) kill floor pH and belly weight as the amount of dietary bakery by-product increased. Pigs fed the 15% bakery by-product diets had the lowest (quadratic, $P < 0.05$) belly temperature and belly firmness score.

The addition of up to 15% dietary bakery by-product resulted in poorer feed efficiency and caloric efficiency on a ME basis. Poorer ME caloric efficiency suggests that the ME value for dietary bakery by-product used was overestimated for the product used in this study. This would be supported by the proximate analysis that showed a lower fat percentage (6.4 vs. 11.3%) in the analyzed bakery by-product samples compared with the expected fat percentage used in diet formulation.

The belly fat IV was increased at a greater rate when increasing the amount of added bakery by-product from 7.5 to 15% compared with the increase from 0 to 7.5%. With the exception of belly fat IV, bakery by-product had few negative effects on the carcass quality parameters measured.

Table 1. Composition of diets (Phases 1, 2, and 3; as-fed basis)[1]

	Bakery by-product, %								
	Phase 1			Phase 2			Phase 3		
	0	7.5	15	0	7.5	15	0	7.5	15
Ingredient,%									
Corn	31.81	24.84	17.78	34.69	27.62	20.65	54.62	47.56	40.59
Soybean meal (46.5% CP)	16.68	16.15	15.73	11.43	11.00	10.48	12.25	11.83	11.30
Bakery by-product	—	7.50	15.00	—	7.50	15.00	—	7.50	15.00
DDGS[2]	47.50	47.50	47.50	50.00	50.00	50.00	30.00	30.00	30.00
Choice white grease	1.45	1.45	1.45	1.35	1.35	1.35	0.95	0.95	0.95
Monocalcium P, (21% P)	—	—	—	—	—	—	—	—	—
Limestone	1.57	1.54	1.51	1.58	1.55	1.52	1.31	1.28	1.25
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-lysine[3]	0.54	0.56	0.58	0.51	0.53	0.55	0.42	0.44	0.46
L-threonine	—	—	—	—	—	—	—	—	—
Phytase[4]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Ractopamine HCl[5]	—	—	—	—	—	—	—	—	—
Total	100	100	100	100	100	100	100	100	100
Calculated analysis									
Standardized ileal digestible amino acids, %									
Lysine	1.02	1.02	1.02	0.88	0.88	0.88	0.80	0.80	0.80
Isoleucine:lysine	75	74	74	78	78	78	75	75	74
Leucine:lysine	205	203	200	229	226	223	212	209	206
Methionine:lysine	37	37	37	41	41	41	38	38	37
Met & Cys:lysine	66	66	66	72	72	72	69	69	69
Threonine:lysine	69	68	68	73	73	72	69	69	68
Tryptophan:lysine	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Valine:lysine	90	90	90	97	97	96	92	92	91
Total lysine	1.23	1.23	1.23	1.08	1.08	1.08	0.96	0.96	0.95
CP, %	23.8	23.8	23.8	22.2	22.3	22.3	18.8	18.8	18.8
ME, kcal/lb[6]	1,549	1,559	1,569	1,547	1,557	1,568	1,543	1,553	1,563
NE, kcal/lb[7]	1,159	1,153	1,147	1,172	1,166	1,160	1,165	1,159	1,152
Ca, %	0.68	0.67	0.67	0.66	0.66	0.65	0.56	0.56	0.55
P, %	0.54	0.54	0.53	0.53	0.53	0.52	0.45	0.45	0.44
Available P, %	0.37	0.37	0.37	0.37	0.37	0.37	0.27	0.27	0.27

[1] Phase 1, 2, and 3 diets were fed from 78 to 137 lb, 137 to 175 lb, and 175 to 203 lb BW, respectively.
[2] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[3] Biolys (50.7% L-lys; Evonik Degussa Corporation, Kennesaw, GA).
[4] OptiPhos 2000 (Enzyvla LLC, Sheridan, NJ), which provided 0.07% available P.
[5] Provided 9 g/lb of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[6] ME values for ingredients were derived from NRC (1998).
[7] NE values for all ingredients except bakery by-product were derived from INRA (2004). Bakery by-product NE value was derived from NRC (1998).

Table 2. Composition of diets (Phases 4 and 5; as-fed basis)[1]

	Bakery by-product, %					
	Phase 4			Phase 5		
	0	7.5	15	0	7.5	15
Ingredient, %						
Corn	69.67	62.60	55.64	63.25	56.29	49.23
Soybean meal (46.5% CP)	13.28	12.85	12.32	18.99	18.46	18.03
Bakery by-product	—	7.50	15.00	—	7.50	15.00
DDGS[2]	15.00	15.00	15.00	15.00	15.00	15.00
Choice white grease	—	—	—	0.70	0.70	0.70
Monocalcium P, (21% P)	0.13	0.13	0.13	—	—	—
Limestone	1.13	1.10	1.07	1.15	1.12	1.09
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.10	0.10	0.10	0.08	0.08	0.08
L-lysine[3]	0.35	0.37	0.39	0.40	0.43	0.45
L-threonine	—	—	—	0.05	0.05	0.05
Phytase[4]	0.005	0.005	0.005	0.007	0.007	0.007
Ractopamine HCl[5]	—	—	—	0.025	0.025	0.025
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.75	0.75	0.75	0.92	0.92	0.92
Isoleucine:lysine	72	72	72	69	69	69
Leucine:lysine	195	192	189	173	171	168
Methionine:lysine	35	34	34	31	31	31
Met & Cys:lysine	67	67	67	60	60	60
Threonine:lysine	66	65	65	67	67	66
Tryptophan:lysine	18.0	18.1	18.0	18.0	18.0	18.0
Valine:lysine	87	87	86	81	81	81
Total lysine	0.87	0.87	0.87	1.06	1.06	1.06
CP, %	16.4	16.5	16.5	18.6	18.6	18.6
ME, kcal/lb[6]	1,524	1,534	1,544	1,539	1,549	1,559
NE, kcal/lb[7]	1,143	1,137	1,131	1,142	1,136	1,130
SID lysine: ME/Mcal	2.23	2.22	2.20	2.71	2.69	2.68
Ca, %	0.52	0.52	0.51	0.53	0.52	0.51
P, %	0.42	0.42	0.41	0.42	0.41	0.41
Available P, %	0.22	0.22	0.22	0.22	0.22	0.22

[1] Phases 4 and 5 were fed from 203 to 225 lb and 225 to 283 lb BW, respectively.
[2] Dried distillers grains with solubles from Valero (Aurora, SD).
[3] Biolys (50.7% L-lys; Evonik Degussa Corporation, Kennesaw, GA)
[4] OptiPhos 2000 (Enzyvla LLC, Sheridan, NJ), which provided 0.07 and 0.08% available P in Phases 4 and 5, respectively.
[5] Provided 9 g/lb of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[6] ME values for ingredients were derived from NRC (1998).
[7] NE values for all ingredients except bakery by-product were derived from INRA (2004). Bakery by-product NE value was derived from NRC (1998).

Table 3. Analyzed nutrient composition of bakery by-product[1]

Item	As-fed basis	Dry matter basis
Moisture, %	8.17	---
DM, %	91.83	100.00
CP, %	13.97 (10.8)	15.23
ADF, %	8.10	8.80
NDF, %	19.00	20.70
Fat (oil), %	6.43 (11.3)	6.97
Ash, %	5.28	5.74

[1] Proximate analysis was analyzed by Ward Laboratories, Inc. (Kearney, NE) and presented as the mean of 3 composite samples. The values in parentheses were values that used in the formulation.

Table 4. Chemical analysis of complete diets (as-fed basis)[1,2]

	Bakery by-product, %														
	Phase 1			Phase 2			Phase 3			Phase 4			Phase 5		
Nutrient,%	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15
DM	89.3	89.8	89.8	89.3	89.9	89.7	89.7	89.8	90.0	88.7	89.2	88.9	88.8	88.9	74.4
CP	21.4	22.1	22.0	19.2	16.9	21.6	18.4	18.2	20.8	15.2	16.7	15.5	16.9	18.0	17.6
Fat (oil)	6.1	7.2	7.7	5.3	5.7	7.8	5.5	6.1	7.9	4.1	4.2	4.5	4.3	4.6	5.0
Crude fiber	5.6	6.2	6.3	4.1	4.3	6.2	4.1	4.5	6.6	3.6	3.45	3.4	3.0	3.3	3.6
ADF	7.2	8.2	8.0	5.8	5.6	8.3	6.0	6.3	8.5	5.6	5.9	5.9	5.2	5.7	6.2
NDF	16.4	18.9	17.5	13.4	14.1	17.8	16.1	14.9	18.4	13.4	12.9	12.9	11.9	13.2	13.7
Ash	5.1	4.9	5.5	3.8	4.0	4.7	3.8	4.1	4.8	3.6	4.1	3.9	4.0	3.9	4.3

[1] Phase 1, 2, 3, 4, and 5 diets were fed from 78 to 137 lb,137 to 175 lb, 175 to 203 lb, 203 to 225 lb, and 225 to 282 lb BW, respectively.
[2] Proximate analysis was analyzed by Ward laboratories, Inc., Kearney, NE.

Table 5. Effects of bakery by-product on growth performance and carcass characteristics of growing and finishing pigs[1]

	Bakery by-product,%				Probability, $P<$	
Item	0	7.5	15	SEM	Linear	Quadratic
d 0 to 75						
ADG, lb	1.96	1.91	1.96	0.02	0.99	0.02
ADFI, lb	5.02	4.99	5.15	0.06	0.14	0.20
F/G	2.57	2.62	2.63	0.03	0.07	0.58
Caloric efficiency[2]						
ME	3,961	4,064	4,117	41	0.01	0.60
NE	2,981	3,022	3,025	30	0.28	0.59
d 75 to 102						
ADG, lb	2.39	2.39	2.34	0.03	0.17	0.48
ADFI, lb	6.67	6.79	6.75	0.07	0.38	0.27
F/G	2.79	2.85	2.88	0.03	0.03	0.67
Caloric efficiency[2]						
ME	4,297	4,418	4,495	45.34	0.01	0.68
NE	3,189	3,240	3,258	33.36	0.13	0.67
d 0 to 102						
ADG, lb	2.06	2.02	2.05	0.01	0.57	0.07
ADFI, lb	5.41	5.42	5.53	0.06	0.15	0.47
F/G	2.63	2.68	2.70	0.02	0.02	0.50
Caloric efficiency[2]						
ME	4,052	4,160	4,218	34	0.001	0.52
NE	3,037	3,081	3,088	25	0.14	0.52
Avg. weight, lb						
d 0	77.9	78.1	77.4	1.30	0.78	0.79
d 75	226.0	222.8	225.1	2.0	0.7	0.2
d 102	284.7	281.5	282.3	2.3	0.44	0.46
d 103[3]	282.9	280.0	282.2	2.3	0.82	0.33
Carcass characteristics[4]						
HCW	213.8	212.3	212.6	1.6	0.60	0.63
Yield (farm), %[5]	75.1	75.4	75.3	0.28	0.55	0.54
Yield (plant), %[6]	75.6	75.8	75.3	0.26	0.53	0.21
Backfat thickness[7]	0.62	0.63	0.61	0.01	0.37	0.33
Loin depth, in.[7]	2.78	2.78	2.79	0.02	0.70	0.89
Lean, %[7,8]	54.0	54.0	54.2	0.1	0.41	0.40

[1] A total of 1,263 pigs (PIC 337 × 1050; initially 77.8 lb) were used in 102-d study, with 25 to 28 pigs per pen and 16 pens per treatment. Five pigs per pen were sold as tops on d 84 of the experiment.
[2] Caloric efficiency is expressed as kcal/lb gain.
[3] Final weight taken at the packing plant prior to harvest.
[4] On d 102, the remaining pigs were individually tattooed by pen number and sent to harvest to allow for collection of carcass data.
[5] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[6] Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant prior to harvest.
[7] Adjusted using HCW as a covariate.
[8] Calculated using NPPC (2001) equation.

Table 6. Effects of bakery by-product on carcass quality[1]

	Bakery by-product				Probability, $P<$	
Item	0%	7.5%	15%	SEM	Linear	Quadratic
d 84[2]						
HCW	200.6	195.4	198.6	2.7	0.59	0.20
Backfat, in.[3]	0.62	0.67	0.70	0.04	0.12	0.87
Lean, %[3,4]	53.2	52.8	52.2	0.6	0.32	0.94
Loin depth, in.[3]	2.23	2.39	2.36	0.06	0.14	0.23
Kill floor, pH	6.6	6.5	6.6	0.1	0.87	0.68
4-h pH	6.6	6.6	6.6	0.1	0.73	0.47
Belly trait						
Temperature,°F	32.3	33.7	33.3	0.8	0.36	0.38
Weight, lb	14.9	14.7	15.1	0.3	0.64	0.45
Thickness, middle, in.	0.92	0.87	0.92	0.03	0.90	0.19
Thickness, edge, in.	1.07	1.08	1.13	0.04	0.25	0.64
Firmness[5]	2.6	2.7	2.7	0.1	0.51	0.53
Belly fat IV	78.7	78.6	80.2	0.6	0.09	0.25
Loin pH	5.9	5.8	5.9	0.03	0.61	0.31
Loin color[6]	3.3	3.5	3.7	0.1	0.02	0.67
Marbling[7]	1.5	1.6	1.6	0.1	0.20	0.50

continued

Table 6. Effects of bakery by-product on carcass quality[1]

	Bakery by-product				Probability, $P<$	
Item	0%	7.5%	15%	SEM	Linear	Quadratic
d 102[8]						
HCW	209.1	203.3	210.9	3.2	0.69	0.08
Backfat, in.[3]	0.64	0.61	0.60	0.02	0.21	0.77
Lean, %[3,4]	53.8	54.4	54.5	0.39	0.20	0.60
Loin depth, in.[3]	2.78	2.86	2.83	0.06	0.48	0.46
Kill floor, pH	6.7	6.5	6.5	0.1	0.09	0.45
4-h pH	6.5	6.5	6.5	0.05	0.65	0.63
Belly trait						
Temperature,°F	33.6	31.1	32.0	0.7	0.13	0.05
Weight, lb	16.7	15.7	15.9	0.3	0.09	0.15
Thickness, middle, in.	1.08	1.07	0.99	0.03	0.04	0.38
Thickness, edged, in.	1.20	1.16	1.09	0.03	0.01	0.73
Firmness[5]	2.1	1.8	2.1	0.1	0.79	0.03
Belly fat IV	75.2	76.0	81.1	1.0	0.001	0.07
Loin pH	5.8	5.8	5.8	0.03	0.74	0.46
Loin color[6]	3.5	3.3	3.4	0.2	0.71	0.65
Marbling[7]	1.7	1.4	1.5	0.1	0.24	0.19

[1] A total of 1263 pigs (PIC 337 × 1050; initially 77.8 lb) were used in a 102-d study with 25 to 28 pigs per pen and 16 pens per treatment.

[2] Five pigs per pen were sold as tops on d 84 of the experiment. The median-weight pig was subsampled for collection of carcass quality measurements. Values represent the treatment means with 1 pig per pen.

[3] Adjusted using HCW as a covariate.

[4] Calculated using NPPC (2001) equation.

[5] Scored on scale: 1 = none to very little bend, 2 = moderate or 50% bend, 3 = belly ends touched.

[6] Scored on a scale from 1 to 6, with 1 = pale and 6 = dark.

[7] Scored on scale from 1 to 10, with 1 = very little to no intramuscular lipid content and 10 = extreme amounts.

[8] The middle-weight pig of the remaining pigs in the pen was subsample for collection of carcass quality measurements. Values represent the treatment means with 1 pig per pen.

The Effects of Wheat and Crystalline Amino Acids on Nursery and Finishing Pig Growth Performance and Carcass Characteristics[1]

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Summary

Two experiments were conducted to evaluate the effects of wheat and crystalline amino acids on growth performance of nursery and finishing pigs. In Exp. 1, a total of 192 pigs (PIC, 337 × 1050, initially 26.7 lb BW) were used in a 21-d nursery study. Pigs were allotted to pens by initial BW, and pens were assigned to 1 of 4 dietary treatments in a completely randomized design with 6 pigs per pen and 8 replications per treatment. Treatments included: (1) corn-soybean meal diet, (2) diet 1 with wheat replacing approximately 50% of the corn, (3) wheat replacing 100% of the corn in diet 1 with high amounts of crystalline amino acids, and (4) diet 3 with 5% more SBM and lower crystalline amino acids. Overall, (d 0 to 20), no growth performance differences were found when replacing 50% of corn with wheat ($P > 0.75$), but tendencies for reduced ADG (linear, $P < 0.08$) were observed when replacing 100% corn with wheat. Replacing 100% of corn with wheat improved (linear, $P < 0.05$) caloric efficiency on an ME basis and tended to improve (linear, $P < 0.07$) caloric efficiency on an NE basis. Adding more soybean meal to all wheat diets tended to improve ($P < 0.07$) F/G and improved ($P < 0.03$) caloric efficiency on an NE basis.

In Exp. 2, 288 pigs (PIC 327 × 1050, initially 159.5 lb BW) were used in a 61-d finishing study. Pens of pigs (8 or 7 pigs per pen) were randomly allotted by initial BW to 1 of 4 dietary treatments with 9 replications per treatment. Treatments were fed in two phases and were similar to Exp. 1 with: (1) corn-soybean meal diet, (2) diet 1 with wheat replacing approximately 50% of the corn, (3) wheat replacing 100% of the corn in diet 1 with high amounts of crystalline amino acids, and (4) diet 3 with soybean meal replacing a portion of the crystalline amino acids in diet 3. Overall (d 0 to 61), pigs fed increasing wheat had decreased ADG (linear, $P < 0.04$) and poorer F/G (linear, $P < 0.003$), which was primarily due to worsening of each when wheat was fed at 100% compared with 50% of the diet. Replacing corn with wheat tended to improve (linear, $P < 0.08$) caloric efficiency on an ME basis, but not on an NE basis. Adding more soybean meal to low amount of crystalline amino acids in wheat-based diets had no effect ($P > 0.32$) on growth performance.

A tendency for increased backfat ($P < 0.08$) was observed for pigs fed 50% wheat compared with 100% corn. Jowl fat iodine value (IV) decreased (linear, $P < 0.001$) with increasing wheat.

[1] Appreciation is expressed to Triumph Foods LLC (St. Joseph, MO) for collecting jowl fat and conducting the iodine value analysis and to Jerry Lehenbauer, David Donovan, Derek Petry, Ann Smith, and Brad Knadler for technical assistance.
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In summary, wheat can be used to replace 50% of corn in finishing pig diets without negatively affecting growth performance; at the same time, pigs fed wheat-based diets had improved carcass fat IV. Use of high levels of crystalline amino acids in wheat-based diets did not influence growth performance of nursery or finishing pigs.

Key words: amino acids, finishing pig, nursery pig, wheat

Introduction

With near-record drought conditions in the Midwest causing increases in the price of corn and soybean meal, wheat has potential to become a more common ingredient in swine diets. Wheat is routinely used in diets in other countries. Wheat has higher standardized digestibility of certain amino acids, such as lysine and tryptophan, along with a higher CP and available P; however, due to low oil content, wheat is lower in dietary energy than corn. Wheat has an amino acid profile that allows for higher inclusion rates of crystalline amino acids than in corn-based diets; in fact, crystalline amino acids can be used to replace all of the soybean meal in late finishing diets. Little data with current genetics is available on the effects of these high inclusion rates of crystalline amino acids in wheat-based diets, so these experiments were conducted to determine the effects of replacing corn with wheat and the influence of crystalline amino acid levels in wheat diets on growth performance of nursery and finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in both experiment. The both studies were conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. Wheat and corn samples used in both experiments were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis (Table 1).

In Exp. 1, a total of 192 pigs (PIC 327 × 1050, initially 26.7 lb) were used in a 21-d growth trial. Pigs were allotted to pens by initial BW, and pens were assigned to 1 of 4 dietary treatments in a completely randomized design with 6 pigs per pen and 8 replications per treatment. Dietary treatments included: (1) a corn-soybean meal diet, (2) diet 1 with wheat replacing approximately 50% of the corn, (3) wheat replacing 100% of the corn in diet 1 with high levels of crystalline amino acids, and (4) diet 3 with 5% more soybean meal and low crystalline amino acids (Table 2). Crystalline amino acids (lysine, threonine, and methionine) were added to the corn and wheat diets (diets 1 and 3) until another amino acid became limiting. Tryptophan was the fourth limiting amino acid in the corn-based diet, and valine was the fourth limiting amino acid in the wheat-based diet. Then, diet 2 was formed to have similar levels of corn and wheat in both diets. The soybean meal level was increased by 5% in diet 4 to reduce the level of crystalline amino acids. All diets were formulated to a constant standardized ileal digestible (SID) lysine level of 1.26% as required by diet 1 (highest-energy diet). Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G. Each pen contained a 4-hole, dry self-feeder and a nipple water to provide ad libitum access to feed and water. Pens had wire-mesh floors and allowed approximately 3 ft^2/pig.

In Exp. 2, a total of 288 pigs (PIC 327 × 1050, initially 159.5 lb BW) were used in a 61-d growth trial. Pens of pigs (7 or 8 pigs per pen) were randomly allotted by initial BW to 1 of 4 dietary treatments with 9 replications per treatment. Dietary treatments were similar to Exp. 1 and included: (1) corn-soybean meal diet, (2) diet 1 with wheat replacing approximately 50% of the corn, (3) wheat replacing 100% of the corn in diet 1 with high amounts of crystalline amino acids, and (4) diet 3 with soybean meal replacing a portion of the crystalline amino acids. Diets were fed in 2 approximately 30-d phases from 150 to 210 lb and 210 to 280 lb (Table 3). All diets were formulated to a constant SID lysine level within phase. Diets were fed via the FeedPro system (Feedlogic Corp, Willmar MN). Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. On d 61, all pigs were individually weighed and tattooed for carcass data collection and transported to Triumph Foods LLC, St. Joseph, MO. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat, loin depth, and percentage lean. Jowl fat samples were collected and analyzed by Near Infrared Spectroscopy at the plant for IV. Percentage yield was calculated by dividing HCW at the plant by live weight at the farm.

All diets were fed in meal form and prepared at the K-State Animal Science Feed Mill in Manhattan, KS. Feed samples were collected from all feeders during each phase and subsampled into composite samples of each treatment for each phase to measure bulk densities (Tables 2 and 3).

Data were analyzed as a completely randomized design using the PROC MIXED procedure (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Linear and quadratic contrasts were used to determine the effects of wheat replacing 50 or 100% of the corn (Treatments 1, 2, and 3) and the effects of low vs. high amounts of crystalline amino acids in wheat diets (Treatments 3 vs. 4) and the corn diet compared with the 50% wheat replacement (Treatment 1 vs. 2). Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common carcass weight using HCW as a covariate. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

The analyzed nutrient levels of the wheat and corn used in the experiment were similar to those used in diet formulation (Table 1). Adding increasing amounts of wheat to the diets increased the bulk densities of the diets in both experiments.

In Exp. 1, no differences ($P > 0.75$) in growth performance were observed for the overall trial (d 0 to 21) when replacing 50% of corn with wheat (Table 4). Tendencies were observed for reduced ADG (linear, $P < 0.08$) when replacing 100% of corn with wheat, because dietary energy decreased (Tables 3 and 4) with increasing wheat. Replacing 100% of corn with wheat improved (linear, $P < 0.05$) caloric efficiency on an ME basis and tended to improve (linear, $P < 0.07$) caloric efficiency on an NE basis. Adding more soybean meal to the wheat-based diets tended to improve ($P < 0.07$) F/G and improved ($P < 0.03$) caloric efficiency on an NE basis, indicating that either NE was underestimated in the diet containing extra soybean meal or the extra soybean meal increased the SID amino acids that come from the addition of soybean meal, such as valine or tryptophan, which were beneficial to the nursery pigs.

Overall (d 0 to 61) in Exp. 2, increasing levels of wheat decreased (linear, $P < 0.04$) ADG and worsened (linear, $P < 0.003$) F/G, which was caused by the decrease in dietary energy when increasing amounts of wheat were included (Table 5). Caloric efficiency tended to be improved (linear, $P < 0.08$) on an ME basis with increasing amounts of wheat, but not on an NE basis, suggesting that NE was a more appropriate measure of dietary energy. Adding soybean meal to the wheat-based diets to lower the levels of crystalline amino acids had no effect ($P > 0.32$) on growth performance.

A tendency was observed for pigs fed 50% wheat to have increased ($P < 0.08$) backfat depth compared with pigs fed the corn-based diet. Due to the low oil content in wheat, increasing wheat in the diet reduced (linear, $P < 0.001$) jowl fat IV. Differing levels of crystalline amino acids had no effect on carcass characteristics.

In summary, wheat can be used to replace 50% of corn in nursery or finishing swine rations without negatively affecting growth performance or carcass characteristics; however, growth rate and feed efficiency were worse when wheat completely replaced corn in the diet. These data also showed that adding maximum levels of crystalline amino acids (lysine, methionine, and threonine until the next limiting amino acid is reached) does not have a major influence on pig performance. Further investigation in nursery diets may be warranted due to the numerically poorer feed efficiency at the highest crystalline amino acid inclusion. Finally, feeding wheat lowers carcass fat IV compared with feeding corn, thus creating a more saturated fat that is more desired by processors.

Table 1. Chemical analysis of wheat (as-fed basis)

	Corn	Wheat	
Item	Exp. 1 and 2	Exp. 1	Exp. 2
Nutrient, %			
DM	88.01	89.1	89.2
CP	8.2 (8.5)[1]	12.3 (13.5)[1]	12.3 (13.5)
Fat (oil)	3.3 (3.9)	1.8 (2.0)	1.9 (2.0)
Crude fiber	1.7 (2.2)	2.6 (2.2)	2.5(2.2)
ADF	2.5	3.8	3.2
NDF	7.9	11.1	9.0
Ca	0.05 (0.03)	0.06 (0.06)	0.06 (0.06)
P	0.32 (0.28)	0.39 (0.37)	0.40 (0.37)

[1] Values in parentheses indicate those used in diet formulation.

Table 2. Diet composition in Exp. 1 (as-fed basis)

	Wheat replacement of corn, %:			
Ingredient, %	0	50	100	100 + SBM[1]
Corn	62.42	33.62	--	--
Soybean meal, 46.5% CP	32.08	29.16	25.45	30.46
Hard red winter wheat	--	33.70	70.80	66.30
Monocalcium P, 21% P	1.05	0.95	0.75	0.80
Limestone	1.00	1.05	1.15	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-lysine HCl	0.33	0.39	0.475	0.318
DL-methionine	0.125	0.115	0.095	0.055
L-threonine	0.125	0.145	0.160	0.100
Phyzyme 600[2]	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.26	1.26	1.26	1.26
Isoleucine:lysine	61	61	59	66
Leucine:lysine	129	120	109	119
Methionine:lysine	33	32	30	29
Met & Cys:lysine	58	58	58	58
Threonine:lysine	63	63	63	63
Tryptophan:lysine	17.5	18.5	19.4	21.2
Valine:lysine	68	68	66	73
Total lysine, %	1.39	1.39	1.38	1.39
ME, kcal/lb	1,503	1,472	1,435	1,442
NE, kcal/lb	1,074	1,053	1,029	1,021
SID lysine:ME, g/Mcal	3.80	3.88	3.98	3.96
CP, %	20.9	21.5	22.0	23.5
Crude fiber, %	2.7	2.6	2.6	2.6
ADF	3.5	3.9	4.2	4.3
NDF	9.0	10.4	11.8	11.7
Ca, %	0.70	0.70	0.70	0.70
P, %	0.62	0.62	0.60	0.62
Available P, %	0.42	0.42	0.42	0.42
Bulk density, lb/bu[3]	58.1	59.6	61.4	62.6

[1] SBM: soybean meal.

[2] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with a release of 0.10% available P.

[3] Diet samples collected from the top of each feeder during each phase.

Table 3. Diet composition in Exp. 2 (as-fed basis)

	Phase 1[1]				Phase 2[1]			
Wheat replacement of corn, %:	0	50	100	100 + SBM[2]	0	50	100	100 + SBM
Ingredient, %								
Corn	81.89	44.39	--	--	85.97	46.58	--	--
SMB, 46.5% CP	16.04	9.15	1.57	2.50	12.06	4.86	--	2.51
Hard red winter wheat	--	44.30	96.05	95.20	--	46.50	97.85	95.45
Monocalcium P, 21% P	0.24	0.06	--	--	0.21	0.03	--	--
Limestone	1.01	1.03	1.09	1.09	0.99	1.00	1.09	1.09
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
L-lysine HCl	0.150	0.330	0.525	0.496	0.150	0.338	0.446	0.368
DL-methionine	--	0.005	0.025	0.023	--	--	0.013	--
L-threonine	--	0.065	0.130	0.120	--	0.068	0.098	0.065
Phyzyme 600[3]	0.125	0.125	0.038	0.038	0.125	0.125	0.028	0.028
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lysine	0.72	0.72	0.72	0.72	0.62	0.62	0.62	0.62
Isoleucine:lysine	71	62	53	55	71	61	58	64
Methionine:lysine	31	29	29	29	33	30	30	30
Met & Cys:lysine	64	63	65	66	68	67	72	73
Threonine:lysine	63	63	63	63	65	65	65	65
Tryptophan:lysine	18.8	18.8	19.3	19.9	18.4	18.5	21.3	23.2
Valine:lysine	83	75	66	68	86	76	73	80
Total lysine, %	0.82	0.80	0.79	0.79	0.71	0.69	0.68	0.69
ME, kcal/lb	1,519	1,482	1,436	1,437	1,522	1,482	1,435	1,436
NE, kcal/lb	1,132	1,115	1,092	1,090	1,145	1,127	1,096	1,090
CP, %	14.6	14.4	14.3	14.6	13.1	12.9	13.7	14.5
Crude fiber, %	2.4	2.3	2.2	2.2	2.4	2.2	2.2	2.2
ADF	3.2	3.5	3.9	3.9	3.1	3.4	3.9	4.0
NDF	9.3	11.1	13.1	13.1	9.3	11.2	13.2	13.1
Ca, %	0.51	0.47	0.48	0.48	0.48	0.44	0.47	0.48
P, %	0.39	0.36	0.37	0.37	0.37	0.34	0.36	0.37
Available P, %	0.11	0.13	0.18	0.18	0.10	0.12	0.18	0.18
Bulk density, lb/bu[4]	56.0	59.6	62.7	62.2	56.0	59.9	62.4	64.0

[1] Phase 1 diets were fed from d 0 to d 30; Phase 2 from d 30 to 61.
[2] SBM: soybean meal.
[3] Phyzyme 600 (Danisco, Animal Nutrition, St. Louis, MO), providing 231 phytase units (FTU)/lb, with a release of 0.10% available P.
[4] Diet samples collected from the top of each feeder during each phase.

Table 4. Effects of wheat and crystalline amino acids on nursery pig performance[1]

	Wheat replacement of corn, %					Probability, $P<$			
						Wheat			
Item	0	50	100	100 + SBM[2]	SEM	Linear[3]	Quadratic[4]	0 vs. 50%	Extra SBM[5]
d 0 to 21									
ADG	1.21	1.22	1.15	1.19	0.021	0.08	0.16	0.75	0.23
ADFI	1.90	1.92	1.84	1.84	0.037	0.25	0.32	0.77	0.99
F/G	1.57	1.57	1.59	1.55	0.018	0.44	0.70	0.99	0.07
Caloric efficiency[6]									
ME	2,364	2,315	2,285	2,227	26.6	0.05	0.78	0.21	0.13
NE	1,689	1,656	1,639	1,577	19.0	0.07	0.75	0.24	0.03
Wt, lb									
d 0	26.7	26.7	26.7	26.7	2.7	0.99	0.99	0.99	0.98
d 21	52.1	52.3	50.9	51.7	4.1	0.24	0.36	0.84	0.42

[1] A total of 192 pigs (PIC 327 × 1050, initially 26.7 lb) were used in a 21-d study with 8 replications per treatment.
[2] SBM: soybean meal. Similar to diet with wheat replacing 100% of corn, except more SBM and lower crystalline amino acid levels were used.
[3] Comparison of 0%, 50%, and 100% with high amino acids.
[4] Comparison of 0%, 50%, and 100% with high amino acids.
[5] 100% vs. 100% + SBM.
[6] Caloric efficiency is expressed as kcal/lb gain.

Table 5. Effects of wheat and crystalline amino acids on finishing pig performance[1]

	Wheat replacement of corn, %				Probability, $P<$				
						Wheat			
Item	0	50	100	100 + SBM[2]	SEM	Linear[3]	Quadratic[4]	0 vs. 50%	Extra SBM[5]
d 0 to 61									
ADG	1.83	1.81	1.74	1.73	0.028	0.04	0.49	0.64	0.80
ADFI	5.96	5.97	5.89	5.83	0.086	0.56	0.69	0.94	0.61
F/G	3.26	3.30	3.39	3.37	0.029	0.003	0.50	0.32	0.73
Wt, lb									
d 0	159.2	159.5	159.5	159.8	1.89	0.91	0.83	0.90	0.98
d 61	270.9	270.1	265.8	266.1	3.14	0.95	0.29	0.86	0.68
Caloric efficiency[6]									
ME	4,954	4,884	4,850	4,837	40.4	0.08	0.72	0.23	0.82
NE	3,710	3,695	3,696	3,670	30.6	0.76	0.82	0.73	0.55
Carcass characteristics									
Carcass yield, %[7]	73.4	73.5	73.4	73.1	0.19	0.37	0.40	0.51	0.21
HCW, lb	201.9	202.0	198.1	197.4	2.34	0.82	0.18	0.98	0.42
Backfat depth, in.	0.78	0.83	0.83	0.82	0.020	0.15	0.25	0.08	0.78
Loin depth, in.	2.3	2.3	2.3	2.3	0.03	0.87	0.19	0.29	0.42
Lean, %	52.3	52.0	51.9	51.8	0.27	0.31	0.94	0.56	0.75
Jowl fat iodine value	68.9	67.7	67.1	67.4	0.24	0.001	0.35	0.002	0.27

[1] A total of pigs 288 (PIC 327 × 1050, initially 159.5 lb) were used in a 61-d study with 8 replications per treatment.
[2] SBM: soybean meal. Similar to diet with wheat replacing 100% of corn, except more SBM and lower crystalline amino acid levels were used.
[3] Comparison of 0%, 50%, and 100% with high amino acids.
[4] Comparison of 0%, 50%, and 100% with high amino acids.
[5] 100% vs. 100% + SBM.
[6] Caloric efficiency is expressed as kcal/lb gain.
[7] Percentage carcass yield was calculated by dividing HCW by the live weights obtained at the farm before transported to the packing plant.

The Effects of Medium-Oil Dried Distillers Grains with Solubles on Growth Performance and Carcass Traits in Finishing Pigs[1]

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Summary

An experiment was conducted to determine the effects of increasing medium-oil dried distillers grains with solubles (DDGS; 7.4% fat, 28.1% CP, 10.8% ADF, and 25.6% NDF) on growth performance and carcass traits in finishing pigs. A total of 288 pigs (PIC 327 × 1050; initially 151.8 lb) were allotted to 1 of 4 dietary treatments. Treatments consisted of a corn-soybean meal control diet or the control diet with 15, 30, or 45% medium-oil DDGS, with 8 pigs per pen and 8 replications per treatment. Increasing medium-oil DDGS decreased (linear, $P < 0.01$) ADG and worsened (linear, $P < 0.02$) F/G. In addition, final BW, HCW, carcass yield, and loin-eye depth decreased (linear, $P < 0.03$), and jowl iodine value (IV) increased (linear, $P < 0.001$) with increasing medium-oil DDGS. When pigs are fed traditional DDGS containing >10.5% fat, each 10% DDGS added to the diet increases jowl IV approximately 2 mg/g; however, feeding increasing medium-oil DDGS increased jowl IV only about 1.4 units per each 10% DDGS. In conclusion, swine producers must be aware of the negative ramifications on growth performance of using medium-oil DDGS in swine diets.

Key words: DDGS, finishing pig, iodine value, medium-oil DDGS

Introduction

Dried distillers grains with solubles are a by-product of the ethanol industry that are commonly used in the United States to lower diet costs. Research suggests that growth performance will remain unchanged if traditional (>10.5% oil) DDGS are fed at up to 30% of the diet (Stein and Shurson, 2009[3]), but carcass characteristics such as yield and jowl IV are adversely affected with feeding DDGS. Jowl IV is a measure of the unsaturated fat content, and as IV increases, pork fat becomes softer and less desirable.

Many ethanol plants have begun to remove a portion of the oil from DDGS, thus altering its chemical composition. A concern is that the new, medium-oil DDGS may negatively affect ADG and F/G because of its low energy content; however, the medium-oil DDGS may not have as negative of an effect on fat IV and carcass traits as traditional DDGS. The objective of this trial was to determine the effects of increasing medium-oil

[1] Appreciation is expressed to Triumph Foods LLC (St. Joseph, MO) for collecting jowl fat and conducting the IV analysis; to Jerry Lehenbauer, David Donovan, Derek Petry, Ann Smith, and Brad Knadler for technical assistance; and to Rob Musser, NutriQuest, Mason City, IA, for analysis of the DDGS used in this study.

[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[3] Stein, H. H., and G. C. Shurson. 2009. Board-Invited Review: The use and application of distillers dried grains with solubles (DDGS) in swine diets. J. Anim. Sci. 87:1292–1303.

DDGS on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The experiment was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

A total of 288 finishing pigs (PIC 327 × 1050, initially 151.8 lb) were used in a 67-d study. Pens of pigs were allotted to 1 of 4 dietary treatments with 8 pigs per pen and 8 replications per treatment. The facility was a totally enclosed, environmentally controlled, mechanically ventilated barn containing 36 pens. The pens (8 ft × 10 ft) had adjustable gates facing the alleyway that allowed for 10 ft^2/pig. Each pen was equipped with a cup waterer and a Farmweld (Teutopolis, IL) single-sided, dry self-feeder with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A single batch of medium-oil DDGS was used in this study and analyzed for chemical composition (Table 1). The DDGS contained 7.4% fat, 28.1% CP, 10.8% ADF, and 25.6% NDF. Fatty acid analysis was conducted of the medium-oil DDGS at the K-State Analytical Lab (Manhattan, KS; Table 2). At the time of diet formulation, the 2012 NRC publication was not available; therefore, Stein et al. (2007[4]) values for amino acids were used in diet formulation. Pigs were fed corn-soybean meal–based diets containing 0, 15, 30, or 45% medium-oil DDGS. Diets were fed in 2 phases from approximately 150 to 220 and 220 to 280 lb (Tables 3 and 4). All pigs and feeders were weighed on d 0, 33, and 67 to determine ADG, ADFI, and F/G.

On d 67, all pigs were weighed and transported approximately 2.5 h (160 miles) to Triumph Foods LLC, St. Joseph, MO. Before slaughter, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage carcass yield, backfat, loin depth, and percentage lean. Because HCW differed, it was used as a covariate for backfat, loin depth, and percentage lean. Also, jowl fat samples were collected and analyzed by Near Infrared Spectroscopy at the plant for IV. Percentage carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant.

Data were analyzed in a completely randomized design with pen as the experimental unit. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Linear and quadratic contrasts were used to determine the effects of increasing medium-oil DDGS.

[4] Stein, H. H. 2007. Feeding distillers dried grains with solubles (DDGS) to swine. Swine Focus #001. University of Illinois Extension publication.

Results and Discussion

Traditional DDGS contains approximately 10.5% oil or greater. After the oil is removed from DDGS by the process of centrifugation, the chemical composition of medium-oil DDGS (approximately 7% oil) is different than that of traditional DDGS (Table 1). Traditional DDGS are lower in crude fiber and starch content than medium-oil DDGS, whereas NDF is lower in medium-oil DDGS than in traditional DDGS[5]. Lysine in medium-oil DDGS is greater (0.90% vs. 0.77%) than in traditional DDGS, but other amino acids remain consistent. The analyzed amino acid levels in the DDGS were greater than those used in diet formulation, so diets containing DDGS contained slightly higher lysine and other amino acids than calculated in diet formulation. The lower amount of fat/energy in medium-oil DDGS compared with traditional DDGS is the reason for concern for growth performance in finishing pigs. Because energy content of DDGS is the most important factor determining its value relative to corn, a reduction in energy content of the DDGS significantly reduces its feeding value.

In this experiment, pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.01$) ADG and poorer (linear, $P < 0.02$) F/G (Table 5). As a result, pigs fed DDGS had lighter (linear, $P < 0.03$) final BW than those fed the corn-soybean meal–based diet. Pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.01$) HCW, backfat, and loin-eye depth. Increasing medium-oil DDGS also increased jowl IV (linear, $P < 0.001$.

When feeding traditional DDGS (>10.5% oil), growth performance typically remains unchanged with an inclusion rate up to 30%, but jowl IV increases because of the unsaturated fat. Typically, for every 10% traditional DDGS added to the diet, jowl IV increases approximately 2 mg/g; however, in this study with the medium-oil DDGS, IV increased only 1.4 mg/g for every 10% inclusion. Thus, the IV increase for medium-oil DDGS is approximately 70% of the increase with high-oil DDGS. This difference was expected because the oil content in the medium-oil DDGS (7.4%) is approximately 70% of the oil content in high-oil DDGS (10.5%).

In conclusion, increasing medium-oil DDGS in finishing pig diets reduced growth performance such that it needs to be discounted in value relative to regular DDGS when adding to swine diets.

[5] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington, DC.

Table 1. Comparison of dried distillers grains with solubles (DDGS) sources

		NRC 2012[1]		
Item	Medium-oil DDGS[2]	Low-oil DDGS[3]	Medium-oil DDGS[4]	Traditional DDGS[5]
Nutrient, %				
DM	89.9	89.25	89.35	89.31
CP	28.1	27.86	27.36	27.33
Crude fiber	7.14	6.19	8.92	7.06
Ether extract (Fat)	7.4	3.57	8.9	10.43
Ash	4.35	4.64	4.04	4.11
Starch	7.6	10.0	9.6	6.7
NDF	25.60	33.75	30.46	32.50
ADF	10.8	16.91	12.02	11.75
Amino acids, %				
Cysteine	---	0.51	0.44	0.51
Isoleucine	1.11	1.02	1.06	1.02
Leucine	3.38	3.64	3.25	3.13
Lysine	0.92	0.68	0.90	0.77
Methionine	0.53	0.50	0.57	0.55
Threonine	1.03	0.97	0.99	0.99
Tryptophan	0.23	0.18	0.20	0.21
Valine	1.46	1.34	1.39	1.35
Energy, kcal/kg				
GE	---	2,317	2,141	2,204
DE	---	1,496	1,628	1,645
ME	---	1,410	1,544	1,561
NE	---	913	1,065	1,084

[1] NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC.
[2] Values represent the mean of 1 composite sample analyzed in triplicate.
[3] Defined as corn DDGS, <4% oil.
[4] Defined as corn DDGS, >6 and <9% oil.
[5] Defined as corn DDGS, >10% oil.

Table 2. Fatty acid analysis of medium-oil dried distillers grains with solubles (DDGS)

Item	Medium-oil DDGS
Myristic acid (C14:0), %	0.08
Palmitic acid (C16:0), %	13.69
Palmitoleic acid (C16:1), %	0.15
Margaric acid (C17:0), %	0.11
Stearic acid (C18:0), %	1.86
Oleic acid (C18:1 cis-9), %	22.50
Vaccenic acid (C18:1n-7), %	1.25
Linoleic acid (C18:2n-6), %	56.75
α-Linoleic acid (C18:3n-3), %	1.80
Arachidic acid (C20:0), %	0.41
Gadoleic acid (C20:1), %	0.24
Eicosadienoic acid (C20:2), %	0.08
Arachidonic acid (C20:4n-6), %	0.05
Other fatty acids, %	1.00
Total SFA, %[1]	16.15
Total MUFA, %[2]	24.19
Total PUFA, %[3]	58.70
Total trans fatty acids, %[4]	0.15
UFA:SFA ratio[5]	5.13
PUFA:SFA ratio[6]	3.63
Iodine value,g/100g[7]	122.7

[1] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] +[C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[2] Total MUFA = ([C14:1] + [C16:1] + [C18:1 cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[3] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[4] Total *trans* fatty acids = ([C18:1 trans] + [C18:2 trans] + [C18:3 trans]); brackets indicate concentration.
[5] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[6] PUFA:SFA = total PUFA/total SFA.
[7] Calculated as iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 3. Composition of diets from d 0 to 33 (as-fed basis)[1]

	Medium-oil dried distillers grains with solubles (DDGS), %			
Item	0	15	30	45
Ingredient, %				
Corn	79.00	66.83	54.80	42.45
Soybean meal, 46.5% CP	18.48	15.84	13.04	10.41
Medium-oil DDGS[2]		15.00	30.00	45.00
Monocalcium P, 21% P	0.90	0.55	0.20	
Limestone	0.89	1.03	1.17	1.32
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10
L-lysine HCl	0.18	0.21	0.24	0.27
L-threonine	0.01			
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lysine	0.80	0.80	0.80	0.80
Isoleucine:lysine	68	73	77	81
Leucine:lysine	165	190	215	239
Methionine:lysine	29	34	38	43
Met & Cys:lysine	60	65	70	76
Threonine:lysine	61	66	71	76
Tryptophan:lysine	18	19	18	19
Valine:lysine	80	87	93	101
Total lysine, %	0.90	0.93	0.96	0.99
CP, %	15.48	17.32	19.11	20.95
Ca, %	0.59	0.57	0.55	0.56
P, %	0.54	0.52	0.50	0.51
Available P, %	0.25	0.25	0.25	0.28

[1] Diets were fed from approximately 152 to 220 lb.

[2] Amino acid values used in diet formulation for the medium-oil DDGS were derived from Stein et al. (2007) for values of traditional DDGS.

Table 4. Composition of diets from d 33 to 72 (as-fed basis)[1]

	Medium-oil dried distillers grains with solubles (DDGS), %			
Item	0	15	30	45
Ingredient, %				
Corn	82.71	70.55	58.52	45.99
Soybean meal, 46.5% CP	14.96	12.31	9.52	6.90
Medium-oil DDGS[2]		15.00	30.00	45.00
Monocalcium P, 21% P	0.75	0.40	0.05	
Limestone	0.87	1.00	1.14	1.30
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10
L-lysine HCl	0.16	0.19	0.23	0.26
L-threonine	0.01			
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lysine	0.70	0.70	0.70	0.70
Isoleucine:lysine	70	75	79	84
Leucine:lysine	177	206	234	262
Methionine:lysine	31	36	41	47
Met & Cys:lysine	64	70	76	82
Threonine:lysine	64	68	74	80
Tryptophan:lysine	18	19	18	19
Valine:lysine	83	91	99	107
Total lysine, %	0.79	0.82	0.85	0.88
CP, %	14.15	15.98	17.77	19.60
Ca, %	0.54	0.52	0.50	0.54
P, %	0.49	0.47	0.45	0.50
Available P, %	0.21	0.21	0.21	0.27

[1] Diets were fed from approximately 220 to 275 lb.

[2] Amino acid values used in diet formulation for the medium-oil DDGS were derived from Stein et al. (2007) for values of traditional DDGS.

Table 5. Effects of increasing medium-oil dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs[1]

	Medium-oil DDGS, %					Probability, *P*<	
Item	0	15	30	45	SEM	Linear	Quadratic
d 0 to 67							
ADG, lb	1.93	1.87	1.85	1.80	0.02	0.01	0.77
ADFI, lb	6.03	5.97	5.91	5.87	0.07	0.10	0.84
F/G	3.13	3.19	3.20	3.26	0.04	0.02	0.99
BW, lb							
Initial	151.8	151.8	151.8	151.8	1.91	0.99	0.99
Final	280.4	277.0	275.7	273.1	2.35	0.03	0.87
Carcass yield, %[2]	73.98	73.16	72.36	71.84	0.16	0.001	0.35
HCW, lb	205.7	201.4	198.5	195.0	1.82	0.001	0.82
Backfat depth, mm[3]	19.4	19.8	19.4	18.7	0.40	0.17	0.15
Loin depth, mm[3]	61.0	60.0	59.7	57.9	0.81	0.01	0.58
Lean, %[3]	53.1	52.8	52.8	52.7	0.23	0.32	0.65
Jowl iodine value	70.2	71.1	73.7	76.3	0.27	.001	0.01

[1] A total of 288 pigs (PIC 327 × 1050, initially 151.8 lb BW) were used in this 67-d study with 8 pigs per pen and 8 pens per treatment.
[2] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[3] Adjusted by using HCW as a covariate.

Effects of Replacing Soybean Meal with High-Protein Dried Distillers Grains with Solubles on Growth Performance, Carcass Characteristics, and Carcass Fat Quality in Finishing Pigs[1,2]

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Summary

A total of 204 barrows and gilts (PIC, 337 × 1050, initially 129.6 lb) were used in a 73-d study to determine the effects of replacing soybean meal (SBM) with high-protein dried distillers grains with solubles (HPDDGS) on growth performance, carcass characteristics, and carcass fat quality in finishing pigs. Pens of pigs (3 barrows and 3 gilts per pen) were randomly allotted by initial BW to 1 of 4 treatments with 8 or 9 replications per treatment. All pigs were fed diets with 15% HPDDGS for 10 d prior to the start of the study. Treatments included: (1) corn-soybean meal diet with 0.15% crystalline lysine, (2) HPDDGS and crystalline amino acids replacing 50% of the SBM in diet 1, and two diets in which 100% of the SBM was replaced by either: (3) HPDDGS and a high amount of crystalline amino acids or (4) a high amount of HPDDGS and low levels of crystalline amino acids. Diets with low amounts of crystalline amino acids (Treatment 4) contained 10% more HPDDGS to replace SBM than diets with high amounts of crystalline amino acids (Treatment 3). Diets were fed in three 28-d phases (130 to 180 lb, 180 to 240 lb, and 240 to 280 lb) for Phases 1, 2, and 3, respectively. Diets 1 and 3 in all phases were blended (50:50) via the FeedPro system (Feedlogic Corp., Willmar, MN) to make diet 2. Overall, replacing 50% of the SBM with HPDDGS and crystalline amino acids had no effect on growth performance; however, replacing 100% SBM with HPDDGS and crystalline amino acids resulted in decreased ($P < 0.02$) ADG and ADFI but no difference ($P > 0.75$) in F/G. In the two diets where 100% of the soybean meal was replaced with HPDDGS, the amount of added crystalline amino acids had no effect on growth performance.

Jowl fat iodine value (IV) increased (linear, $P < 0.0001$) as HPDDGS replaced 50 or 100% of the SBM, but the high amount of added crystalline amino acids resulted in lower ($P < 0.0001$) jowl IV than diets with low amounts of crystalline amino acids. Similarly, carcass yield decreased ($P < 0.01$) as HPPDDGS replaced 100% of the SBM; however, using high amounts of crystalline amino acids increased ($P < 0.01$) carcass yields compared with low amounts of crystalline amino acids. HPDDGS and crystalline amino acids can replace 50% of SBM in finishing pig diets without negatively affecting growth performance or carcass yield. This result suggests that crystalline amino acids

[1] Appreciation is expressed to Ajinomoto Heartland LLC (Chicago, IL) for partial funding.
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could play a role in mitigating the negative effects of DDGS, such as increased IV and decreased carcass yields.

Key words: amino acids, high-protein DDGS, finishing pig

Introduction

The increase in ethanol production in the last 7 years has resulted in the availability of a wide variety of co-products to livestock producers. Corn distillers products vary in CP and oil content depending on the processing method. Dry defractionation is a front-end process that results in the separation of the corn kernel into the bran, germ, and endosperm segments prior to fermentation. Dry defractionation can result in a high-protein DDGS co-product. Due to higher protein than in traditional DDGS, HPDDGS may be able to replace a greater portion of soybean meal in swine diets. Crystalline amino acids also can be used to replace a portion of soybean meal in the diet. Because HPDDGS provides several essential and nonessential amino acids, it is possible that high amounts of crystalline amino acids in combination with HPDDGS could replace SBM entirely in the diet. This experiment was conducted to determine the effects of replacing SBM with HPDDGS and crystalline amino acids on growth performance, carcass characteristics, and carcass fat quality in finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was also equipped with the FeedPro computerized feeding system, which delivered daily feed additions to each pen.

A total of 204 pigs (PIC 337 × 1050; initially 129.6 lb) were used in a 73-d growth trial. Pens of pigs (3 barrows and 3 gilts per pen) were randomly allotted by initial BW to 1 of 4 dietary treatments with 8 or 9 replications per treatment. Diets were formulated to a constant SID lysine level within phase. Dietary treatments included: (1) a corn-soybean meal diet with 0.15% crystalline lysine, (2) HPDDGS and crystalline amino acids replacing 50% of the SBM in the diet 1, and two diets where 100% of the SBM was replaced by either: (3) HPDDGS and a high amount of crystalline amino acids or (4) a high level of HPDDGS and low levels of crystalline amino acids. Diets with low amounts of crystalline amino acids contained 10% more HPDDGS to replace SBM than diets with high amounts of crystalline amino acids (Tables 1 and 2). Diets were fed in 3 4-week phases from approximately 130 to 180 lb, 180 to 240 lb, and 240 to 280 lb. Diet 2 in all phases was a 50:50 blend of diets 1 and 3 delivered via the FeedPro system.

All diets were fed in meal form and prepared at the K-State Animal Science Feed Mill in Manhattan, KS. Standardized ileal digestible amino acid coefficients for HPDDGS were previously determined by Jacela et al. (2008[5]) and used in diet formulation. The ME value of corn, 1,551 kcal/lb (NRC, 1998[6]), was used in formulation for the ME value of HPDDGS. Samples of HPDDGS were collected at the time of feed manufac-

[5] Jacela et al., Swine Day 2008, Report of Progress 1001, pp. 140–144.

[6] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

ture, and a composite sample was analyzed by Ward Laboratories, Inc. (Kearny, NE) (Table 3).

Feed samples were collected from all feeders during each phase and subsampled into a composite sample of each treatment for each phase to measure bulk density (Table 4). Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. On d 73, all pigs were individually weighed and tattooed for carcass data collection and transported to Triumph Foods LLC (St. Joseph, MO). Standard carcass characteristics were measured and jowl fat samples were collected and analyzed at the plant for IV.

Data were analyzed as a completely randomized design using the PROC MIXED procedure (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Linear and quadratic contrasts were used to determine the effects of HPDDGS and synthetic amino acids replacing 50 or 100% of the SBM (Treatments 1, 2, and 3). The effects of low vs. high amounts of synthetic amino acids (Treatments 3 vs. 4), the control treatment compared with the 50% SBM replacement (Treatment 1 vs. 2), as well as the control treatment vs. the combination of both 100% SBM replacements diets were tested (Treatments 1 vs. 3 and 4). Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Replacing SBM with HPDDGS reduced diet bulk density, with the greatest decrease observed in the diet with HPDDGS and low amounts crystalline amino acids resulting in more HPDDGS in the diet (Table 4; Treatment 4). Overall (d 0 to 73), replacing 50% of the SBM with HPDDGS and crystalline amino acids had no effects on growth performance (Table 5); however, replacing 100% of the SBM with HPDDGS resulted in decreased ADG and ADFI ($P < 0.02$) but did not affect F/G ($P > 0.70$). No differences were observed among pigs fed high or low amounts of crystalline amino acids with HPDDGS to replace 100% of the SBM.

When substituting 50% of SBM with the HPDDGS, no effects on carcass characteristics were observed compared with pigs fed the corn-soybean meal–based diet. On the other hand, replacing 100% of the SBM with HPDDGS resulted in reduced carcass yield, loin depth, and the tendency for reduced HCW. Using high amounts of crystalline amino acids when substituting 100% of the SBM resulted in increased ($P < 0.01$) carcass yield and decreased ($P < 0.01$) jowl IV compared with low amounts of crystalline amino acids. This is a result of lower amounts of HPDDGS used in the diets with high amounts of crystalline amino acids compared with the diet with low amounts of crystalline amino acids.

In summary, HPDDGS can be used in combination with crystalline amino acids to replace 50% of the SBM in finishing diets without negatively affecting growth performance and carcass yield. High amounts of crystalline amino acids also may play an important role in mitigating some of the negative effects such as reduced carcass yields and increased jowl IV of corn fermentation co-products.

Table 1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1				Phase 2			
HPDDGS[2] replacement of SBM, %:	0	50	100 w/ high AA[3]	100 w/ low AA	0	50	100 w/ high AA	100 w/ low AA
Ingredient, %								
Corn	76.13	71.74	67.35	57.40	81.55	75.85	70.14	60.19
Soybean meal, 46.5% CP	21.62	10.82	--	--	16.44	8.23	--	--
HPDDGS	--	15.00	30.00	40.00	--	13.75	27.50	37.50
Monocalcium P, 21% P	0.40	0.20	--	--	0.25	0.13	--	--
Limestone	1.00	1.05	1.10	1.20	0.96	1.02	1.09	1.18
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
Trace mineral premix	0.13	0.13	0.13	0.13	0.10	0.10	0.10	0.10
L-lysine HCl	0.15	0.39	0.64	0.57	0.15	0.32	0.49	0.42
L-threonine	--	0.06	0.11	0.05	--	0.03	0.05	--
L-tryptophan	--	0.04	0.08	0.07	--	0.03	0.06	0.05
Phytase 600[4]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids,%								
Lysine	0.86	0.86	0.86	0.86	0.73	0.73	0.73	0.73
Methionine:lysine	29	31	34	39	31	35	38	45
Met & Cys:lysine	60	62	65	75	64	69	74	85
Threonine:lysine	62	62	62	62	63	63	63	65
Tryptophan:lysine	19.2	19.2	19.2	19.2	18.8	18.8	18.8	18.8
Total lysine, %	0.97	0.99	1.00	1.03	0.83	0.85	0.87	0.90
ME, kcal/lb	1,515	1,521	1,527	1,525	1,520	1,524	1,527	1,525
SID lysine:ME, g/Mcal	2.57	2.56	2.55	2.56	2.18	2.17	2.17	2.17
CP, %	16.7	16.5	16.4	18.7	14.7	15.2	15.6	17.9
Ca, %	0.55	0.50	0.46	0.50	0.49	0.47	0.45	0.49
P, %	0.45	0.41	0.37	0.40	0.39	0.38	0.36	0.39
Available P, %	0.26	0.27	0.27	0.32	0.22	0.24	0.26	0.31

[1] Phase 1 diets were fed from approximately 130 to 180 lb.; Phase 2 diets from 180 to 240 lb.
[2] HPDDGS: high-protein dried distillers grains with solubles.
[3] AA: amino acid.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 272.4 phytase units (FTU)/lb., with a release of 0.11% available phosphorus.

Table 2. Phase 3 diet composition (as-fed basis)[1]

	Phase 3			
HPDDGS[2] replacement of SBM, %:	0	50	100 w/ high AA[3]	100 w/ low AA
Ingredient				
Corn	84.87	82.61	80.34	70.40
Soybean meal, 46.5% CP	13.24	6.62	--	--
HPDDGS	--	8.75	17.50	27.50
Monocalcium P, 21% P	0.20	0.10	--	--
Limestone	0.94	0.96	0.99	1.08
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08
L-lysine HCl	0.15	0.30	0.45	0.39
L-threonine	--	0.04	0.08	0.01
L-tryptophan	--	0.03	0.05	0.04
Phytase 600[4]	0.10	0.10	0.10	0.10
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids,%				
Lysine	0.65	0.65	0.65	0.65
Methionine:lysine	32	34	36	43
Met & Cys:lysine	67	68	70	83
Threonine:lysine	64	64	64	64
Tryptophan:lysine	18.5	18.5	18.5	18.5
Total lysine, %	0.74	0.75	0.76	0.79
ME, kcal/lb	1,523	1,526	1,529	1,527
SID lysine:ME, g/Mcal	1.94	1.93	1.93	1.93
CP, %	13.5	13.3	13.1	15.5
Ca, %	0.46	0.44	0.41	0.45
P, %	0.37	0.35	0.33	0.36
Available P, %	0.21	0.22	0.22	0.26

[1] Phase 3 diets were fed from approximately 240 to 280 lb.
[2] HPDDGS: high-protein dried distillers grains with solubles.
[3] AA: amino acid.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 272.4 phytase units (FTU)/lb, with a release of 0.11% available phosphorus.

Table 3. Chemical analysis of high-protein dried distillers grains with solubles (HPDDGS; as-fed basis)

Item	HPDDGS
Nutrient, %	
DM	91.04
CP	33.0 (33.0)[1]
Fat (oil)	11.4
Crude fiber	11.2 (9.0)
ADF	14.7
NDF	31.7
Ca	0.06 (0.06)
P	0.59 (0.59)

[1] Values in parentheses indicate those used in diet formulation.

Table 4. Bulk density of experimental diets (as-fed basis)[1]

	HPDDGS[2] replacement of soybean meal, %			
Bulk density, lb/bu[3]	0	50	100 w/ high AA[4]	100 w/ low AA
Phase 1	57	53	50	48
Phase 2	58	53	51	48
Phase 3	56	53	51	51

[1] Diet samples were collected from each feeder during each phase.
[2] HPDDGS: high-protein dried distillers grains with solubles.
[3] Phase 1 d 0 to 27; Phase 2 d 27 to 54; Phase 3 d 54 to 73.
[4] AA: amino acid.

Table 5. Effect of replacing soybean meal (SBM) with high-protein dried distillers grains with solubles (HPDDGS) on finishing pig performance[1]

	HPDDGS replacement of SBM, %					Probability, *P*<				
Item	0[2]	50[3]	100 w/ high AA[4]	100 w/ low AA[5]	SEM	Low-level DDGS linear[6]	Low-level DDGS quadratic[7]	Low vs. high AA	Control vs. 50% replace	Control vs. 100% replace
Initial wt, lb	129.5	129.7	131.1	129.7	2.1	0.60	0.79	0.63	0.96	0.74
d 0 to 73										
ADG, lb	2.10	2.10	2.01	1.98	0.03	0.04	0.13	0.56	0.84	0.01
ADFI, lb	6.39	6.43	6.14	6.09	0.09	0.05	0.12	0.73	0.74	0.02
F/G	3.05	3.06	3.06	3.07	0.03	0.88	0.91	0.76	0.86	0.73
Final wt, lb	282.3	283.3	277.7	275.5	3.3	0.33	0.40	0.63	0.83	0.16
Carcass characteristics										
Carcass yield, %[8]	73.1	72.7	72.5	71.6	0.23	0.11	0.75	0.01	0.26	0.01
HCW, lb	206.4	206.6	201.5	197.9	2.79	0.22	0.42	0.36	0.95	0.06
Backfat depth, in.	0.82	0.83	0.82	0.79	0.02	0.87	0.61	0.32	0.72	0.45
Loin depth, in.	2.3	2.3	2.2	2.2	0.04	0.06	0.74	0.45	0.48	0.01
Lean, %	51.8	51.5	51.5	51.7	0.28	0.47	0.68	0.65	0.47	0.56
Jowl fat iodine value	69.8	72.1	74.8	78.0	0.440	0.0001	0.71	0.0001	0.0006	0.0001

[1] A total of 204 pigs (PIC 327 x 1050, initial BW 130 lb) were used in a 73-d study with 6 pigs per pen and 8 or 9 pens per treatment.
[2] Corn-soybean meal diet with 0.15% crystalline lysine.
[3] HPDDGS and high amounts of crystalline amino acids replacing 50% of the SBM in diet 1.
[4] HPDDGS and high amounts of crystalline amino acids replacing 100% of the SBM in diet 1.
[5] HPDDGS and low amounts of crystalline amino acids replacing 100% of the SBM in diet 1.
[6] Linear comparisons of low-DDGS treatments (Treatments 1, 2, and 3).
[7] Quadratic comparisons of low-DDGS treatments (Treatments 1, 2, and 3).
[8] Percentage carcass yield was calculated by dividing HCW by the live weights obtained at the farm before transported to the packing plant.

Determining the Effects of Standardized Ileal Digestible Tryptophan:Lysine Ratio and Tryptophan Source in Diets Containing Dried Distillers Grains with Solubles on Growth Performance and Carcass Characteristics of Finishing Pigs[1]

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Summary

A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used to determine the effect of tryptophan source (L-tryptophan vs. soybean meal) and increasing SID tryptophan:lysine ratio in diets containing 30% dried distillers grains with solubles (DDGS) on finishing pig performance. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 7 dietary treatments in a completely randomized design with 26 to 28 pigs per pen and 10 to 13 replications per treatment. Treatments were arranged as a 2 × 3 factorial with main effects of tryptophan source (L-tryptophan or soybean meal) and SID tryptophan:lysine ratio (18, 20, and 22% of lysine). The seventh treatment was a negative control diet formulated to a 16% SID tryptophan:lysine ratio.

Overall, a tryptophan source × SID tryptophan:lysine ratio interaction (linear, $P = 0.03$) was observed for F/G. Increasing SID tryptophan:lysine ratio improved (quadratic, $P < 0.01$) F/G up to 20% when soybean meal was the source of tryptophan, but the optimum was at only 18% when L-tryptophan was added. Increasing the SID tryptophan:lysine ratio increased (linear, $P = 0.01$) carcass yield when using L-tryptophan; however, the greatest yield was observed (quadratic, $P = 0.03$) at 18% SID tryptophan:lysine ratio when soybean meal was used, resulting in a tryptophan source × SID tryptophan:lysine ratio interaction (linear, $P = 0.01$). For the main effect of SID tryptophan:lysine ratio, ADG and F/G improved (quadratic, $P < 0.01$), with increasing SID tryptophan:lysine ratio demonstrating the best performance when SID tryptophan was at 20% of lysine. Loin depth was greatest in the control diet (16% SID tryptophan:lysine ratio) and lowest in 18% SID tryptophan:lysine ratio (quadratic, $P = 0.02$). For the main effect of tryptophan source, no differences were observed in feed intake or feed efficiency among sources of tryptophan; however, we saw a trend ($P = 0.07$) for greater ADG when soybean meal was the tryptophan source. Backfat was greater ($P = 0.04$) and percentage lean ($P = 0.02$) was lower in pigs fed with L-tryptophan than those with soybean meal as the tryptophan source. This study indicated an optimum SID tryptophan:lysine ratio of 20% for 157- to 279-lb pigs. Because using

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance; and to Ajinomoto Heartland LLC (Chicago, IL) for providing partial financial support.
[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.
[3] Ajinomoto Heartland LLC (Chicago, IL).

soybean meal or L-tryptophan provided a similar response in growth performance, the difference in feed cost when adding soybean meal or crystalline tryptophan to the diet will be a major factor in choosing the optimal source of tryptophan.

Key words: amino acids, DDGS, finishing pig, lysine, tryptophan

Introduction

Dried distillers grains with solubles are widely used in swine diets in the United States. Tryptophan is the second limiting amino acid after lysine in diets containing DDGS. A previous study (Barnes et al., 2011[4]) observed a linear increase in ADG and ADFI as the SID tryptophan:lysine ratio increased through 18% of lysine in pigs fed 30% DDGS using soybean meal (SBM) as a source of tryptophan; however, the response was not replicated in a recent trial (Nitikanchana et al., 2011[5]) that used L-tryptophan to increase the SID tryptophan:lysine ratio from 15 to 21%. This result suggests that tryptophan sources (L-tryptophan vs. SBM) may be important to obtain the growth response. Therefore, we conducted this experiment to evaluate tryptophan sources (L-tryptophan vs. SBM) used to increase the SID tryptophan:lysine ratio in diets containing 30% DDGS for finishing pigs from 157 to 279 lb.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment.

The studies were conducted at a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

Two replicated studies were conducted using a total of 2,290 gilts (PIC 1050 × 337) with initial BW of 153 and 161 lb in Exp. 1 and 2, respectively, with 26 to 28 gilts per pen and 10 to 13 pens per treatment. Pens of pigs were assigned to 1 of 7 dietary treatments in a completely randomized design while balancing for initial BW within study. Treatments were arranged as a 2 × 3 factorial with the main effects of tryptophan source (L-tryptophan or SBM) and SID tryptophan:lysine ratio (18, 20, and 22% of lysine) with the addition of a control diet that contained 16% SID tryptophan:lysine. Soybean meal and DDGS sources used in each experiment were analyzed for total amino acid content (Table 1; Ajinomoto Heartland LLC, Chicago, IL). These values along with standardized digestibility coefficients from NRC (1998) for SBM and Stein (2007[6]) for DDGS were used in diet formulation for each study. The SID tryptophan:lysine ratio was increased by adding crystalline tryptophan to the control diet at the expense of corn or by replacing crystalline lysine and corn with SBM. All

[4] Barnes et al., Swine Day 2010, Report of Progress 1038, pp. 156–165.

[5] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 162–167.

[6] Stein, H. H., and G.C. Shurson. 2009. Board-invited review: The use and applicaiton of distillers dried grains with solubles (DDGS) in swine diets. J. Anim. Sci. 87:1292–1303.

diets were fed in meal form and fed in 3 phases from 161 to 205 lb, 205 to 240 lb, and 240 to 270 lb in Exp.1, and 153 to 195 lb, 195 to 244 lb, and 244 to 287 lb in Exp. 2 (Tables 2 through 7). All diets contained 30% DDGS except diets fed in the last phase, in which DDGS level was lowered to 15% to reduce the impact on carcass fat quality and yield. Diets in phase 3 also contained 9 g/ton of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN). Diet samples were collected from feeders during every phase and stored at −20°C, then amino acid analysis was conducted on composite samples by Ajinomoto Heartland LLC.

Pens of pigs were weighed and feed disappearance was recorded at d 22, 40, and 56 in Exp.1 and at d 21, 47, and 68 in Exp. 2 to determine ADG, ADFI, and F/G. On d 40 of Exp. 1 and d 47 of Exp. 2, the 5 heaviest pigs per pen were weighed and sold according to the farm's normal marketing procedure. At the end of the trial, pigs were individually tattooed by pen number to allow for carcass data collection. Pigs were transported to JBS Swift and Company (Worthington, MN) for processing and carcass data collection. Hot carcass weights were measured immediately after evisceration, and carcass criteria of backfat depth, and loin depth were collected using an optical probe. Carcass yield percentage was calculated by dividing live weight at the plant with carcass weight at the plant as reported by the processor, and percentage lean was calculated by the processor using a proprietary equation that depended on backfat and loin depth.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data analysis, and experiment was included in the statistical model as a random effect. Significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively. Analysis of backfat depth, loin depth, and percentage lean were adjusted to a common HCW. Contrast coefficients were used to evaluate linear and quadratic responses to SID tryptophan:lysine ratio (16, 18, 20, and 22%) to compare the two tryptophan sources (L-tryptophan vs. SBM) and to determine linear and quadratic SID tryptophan:lysine ratio by tryptophan source interactions.

Results and Discussion

The analyzed total amino acids were within an acceptable range in both experiments except for a control diet and 22% SID tryptophan:lysine ratio during one phase in Exp. 1 that had a lower lysine level than the formulated value; however, the growth rate was not significantly affected and appeared to be due to random analytic variation. During Phase 1, a linear interaction ($P = 0.04$; Table 8) occurred between tryptophan source and SID tryptophan:lysine ratio for F/G. This was a result of an improvement in F/G (linear, $P < 0.01$; Table 8) when SID tryptophan:lysine ratio was increased using SBM whereas the best F/G (quadratic, $P = 0.13$) was achieved at 18% SID tryptophan:lysine when using L-tryptophan. An interaction in ADG (quadratic, $P = 0.02$) and ADFI (quadratic, $P = 0.01$) was observed during Phase 2 due to the difference in pattern of response between sources. For pigs fed supplemental L-tryptophan, the highest ADG and ADFI was for pigs fed 20% with a slight decrease at 22%, whereas pigs fed with SBM also had the greatest response at 20%, but the response was numerically decreased at 22%. No interaction was detected ($P > 0.25$) during phase 3 when Ractopamine was included in the diets. For the overall period (d 0 to market), an interaction (linear, $P = 0.03$) occurred between tryptophan source and SID tryptophan:lysine ratio for F/G. Increasing the SID tryptophan:lysine ratio improved (quadratic, $P < 0.01$) F/G, with the best F/G observed at 20% of SID lysine when SBM was a source of tryptophan and 18% of lysine when L-tryptophan was the source. For carcass characteristics, increasing the SID tryptophan:lysine ratio increased (linear, $P = 0.01$; Table 8) carcass yield when using L-tryptophan as a tryptophan source; however, the greatest yield was observed (quadratic, $P = 0.03$; Table 8) at an 18% SID tryptophan:lysine ratio when adding SBM resulting in a tryptophan source by SID tryptophan:lysine ratio interaction (linear, $P = 0.01$). An interaction trend also was observed in loin depth (quadratic, $P = 0.08$) and lean percentage (quadratic, $P = 0.07$). Increasing SID tryptophan:lysine ratio with L-tryptophan from 16 to 22% decreased loin depth (quadratic, $P < 0.01$) and lean percentage, but no differences ($P > 0.11$) occurred when increasing tryptophan with SBM.

For the main effects, as the SID tryptophan:lysine ratio increased, ADG tended to improve (quadratic, $P = 0.10$; Table 9) during Phase 1. Feed efficiency improved (linear, $P = 0.05$) when the SID tryptophan:lysine ratio increased, but ADFI was unaffected ($P > 0.41$). During Phase 2, increasing the SID tryptophan:lysine ratio resulted in an increase in ADG (quadratic, $P = 0.09$) and ADFI (linear, $P < 0.01$), but no differences in F/G ($P > 0.19$). The greatest ADG and ADFI were observed at the 20% SID tryptophan:lysine ratio. During Phase 3 when Ractopamine HCl was added to diets, ADG increased (quadratic, $P = 0.01$) and F/G improved (quadratic, $P < 0.01$) up to a 20% SID tryptophan:lysine ratio.

For the overall period (d 0 to market), ADG and F/G improved (quadratic, $P < 0.01$) with the increasing SID tryptophan:lysine ratio, but with no differences in ADFI ($P > 0.44$). This was the result of pigs fed the 20% SID tryptophan:lysine ratio diets having the greatest growth rate and best F/G. For carcass characteristics, pigs fed the 20% SID tryptophan:lysine ratio had the heaviest (quadratic, $P = 0.01$) HCW. Loin depth was greatest in the control diet (16% SID tryptophan:lysine ratio) and was lowest in the pigs fed 18% SID tryptophan:lysine ratio (quadratic, $P = 0.02$). Other carcass characteristics were unaffected ($P > 0.15$) by increasing the SID tryptophan:lysine ratio.

For the main effect of tryptophan source, growth performance during Phase 1 did not differ ($P > 0.55$; Table 10) between pigs fed the two sources of tryptophan. During Phase 2, pigs fed diets with SBM as a source of tryptophan had greater ADG ($P = 0.03$) than those fed diets with L-tryptophan as the source; however, there were no differences ($P > 0.25$) in ADFI or F/G. During Phase 3, ADFI was greater ($P = 0.02$) when using L-tryptophan as a source of tryptophan compared with using SBM, but ADG and F/G ($P > 0.11$) did not differ between pigs fed the two sources of tryptophan. For the overall period, a tendency was observed toward greater ADG ($P = 0.07$) when using SBM as a tryptophan source. Backfat was greater ($P = 0.04$) and percentage of lean was lower ($P = 0.02$) in pigs fed with L-tryptophan as the tryptophan source, but no difference in other carcass characteristics was detected.

In this study, an improvement in yield was observed at 18 and 22% SID tryptophan:lysine ratio when using L-tryptophan as a source of tryptophan, and at 18% when using SBM with no improvement afterward. The influence of the tryptophan:lysine ratio on yield and other carcass traits is not conclusive in this study, but increasing the SID tryptophan:lysine ratio in late finishing pigs fed high levels of

DDGS might offer an opportunity to improve carcass traits, as suggested by Nitikanchana et al. (2011[7,8]).

Increasing the SID tryptophan:lysine ratio from 16 to 22% quadratically improved ADG and F/G, resulting in an optimum SID tryptophan:lysine ratio of 20% for pigs from 157 to 279 lb. The results of this experiment agree with Barnes (2011[9]) that concluded the optimum SID tryptophan:lysine ratio for 160- to 265-lb pigs was at least 18%.

Because SBM or L-tryptophan provided a similar response in growth performance, the difference in feed cost when adding SBM or crystalline tryptophan to the diet will be a major factor in choosing the optimal source of tryptophan in diet formulation; however, our study showed that pigs fed with supplemental L-tryptophan deposited slightly more backfat and had a lower lean percentage. The difference in CP might explain these responses; several trials have reported fatter carcasses with a low-CP, amino acid–fortified diet (Smith et al., 1997[10]; Kerr et al., 1995[11]) compared with the high-CP diet. Only a small difference in CP (2%) was demonstrated in our trials between diets with L-tryptophan and SBM source; other factors may contribute to these responses.

Table 1. Amino acid analysis of soybean meal and dried distillers grains with solubles (DDGS)[1]

	Exp. 1		Exp. 2	
Amino acid, %	Soybean meal	DDGS	Soybean meal	DDGS
Lysine	2.81	0.86	2.74	0.86
Isoleucine	1.99	0.91	1.88	0.90
Leucine	3.30	2.86	3.18	2.76
Methionine	0.59	0.51	0.57	0.49
Cystein	0.63	0.49	0.63	0.46
Met & Cys	1.22	1.00	1.21	0.95
Threonine	1.78	1.00	1.70	0.95
Tryptophan	0.64	0.25	0.58	0.22
Valine	1.99	1.23	1.86	1.15

[1]Soybean meal and dried distillers grains with solubles were analyzed for total amino acid content by Ajinomoto Heartland LLC, Chicago, IL. These values along with standardized digestibility coefficients from NRC (1998) for soybean meal and Stein (2007) for DDGS were used in diet formulation for each study.

[7] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 155–161.
[8] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 168–173.
[9] Barnes et al., Swine Day 2010, Report of Progress 1038, pp. 156–165.
[10] Smith et al., Swine Day 1997, Report of Progress 795, pp. 85–89.
[11] Kerr, B.J., F.K. McKeith, and R.A. Easter. 1995. Effect on performance and carcass characteristics of nursery and finisher pigs fed reduced crude protein, amino acid supplemented diets. J. Anim. Sci. 73:433–440.

Table 2. Composition of diets (Exp. 1, Phase 1, 161 to 205 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	60.30	60.30	57.55–51.91
Soybean meal	7.35	7.35	10.40
DDGS[4]	30.00	30.00	30.00
Limestone	1.25	1.78	1.15–1.10
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.635	0.635	0.485–0.185
L-tryptophan	---	0.016	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.79	0.79	0.78
Isoleucine:lysine	61	61	74
Leucine:lysine	188	188	207
Methionine:lysine	33	33	36
Met & Cys:lysine	66	66	73
Threonine:lysine	60	60	71
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	78	78	90
Phenylalanine:lysine	88	88	103
Tyrosine:lysine	63	63	75
Total lysine, %	0.94	0.94	0.94
ME, kcal/lb	1,526	1,527	1,526
SID lysine:ME, g/Mcal	2.35	2.35	2.32
CP, %	17.2	17.2	19.3
Ca, %	0.50	0.50	0.50
P, %	0.43	0.43	0.46
Available P, %	0.20	0.20	0.21

[1] Phase 1 diet of Exp.1 was fed from 161 to 205 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.

[2] L-tryptophan was added at 0.016, 0.032, and 0.048% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 10.40, 13.37, and 16.38% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.

[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.

[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 3. Composition of diets (Exp.1, Phase 2, 205 to 240 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	64.95	64.95	62.60–57.99
Soybean meal	2.80	2.80	5.30
DDGS[4]	30.00	30.00	30.00
Limestone	1.23	1.23	1.20-1.15
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.545	0.545	0.430–0.205
L-threonine	0.005	0.005	---
L-tryptophan	---	0.013	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.64	0.64	0.64
Isoleucine:lysine	65	65	77
Leucine:lysine	218	218	233
Methionine:lysine	38	38	41
Met & cys:lysine	76	76	82
Threonine:lysine	65	65	75
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	86	86	97
Phenylalanine:lysine	96	96	110
Tyrosine:lysine	68	68	79
Total lysine, %	0.78	0.78	0.79
ME, kcal/lb	1,527	1,527	1,526
SID Lysine:ME, g/Mcal	1.90	1.90	1.90
CP, %	15.4	15.4	17.1
Ca, %	0.50	0.50	0.50
P, %	0.42	0.42	0.44
Available P, %	0.19	0.19	0.20

[1] Phase 2 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.013, 0.026, and 0.038% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 5.30, 7.70, and 10.20% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 4. Composition of diets (Exp. 1, Phase 3, 240 to 270 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	68.91	68.91	65.90–59.62
Soybean meal	13.70	13.70	16.95
DDGS[4]	15.00	15.00	15.00
Limestone	1.13	1.13	1.10-1.05
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.620	0.620	0.470–0.160
L-threonine	0.115	0.115	0.075–0.03
Methionine hydroxy	0.040	0.040	0.010–0
L-tryptophan	---	0.018	---
Phytase[5]	0.01	0.01	0.01
Ractopamine HCl, 9 g/lb[6]	0.05	0.05	0.05
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.88	0.88	0.88
Isoleucine:lysine	59	59	70
Leucine:lysine	158	158	174
Methionine:lysine	32	32	31
Met & Cys:lysine	60	60	62
Threonine:lysine	68	68	69
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	70	70	81
Phenylalanine:lysine	79	79	93
Tyrosine:lysine	57	57	68
Total lysine, %	1.01	1.01	1.02
ME, kcal/lb	1,526	1,527	1,524
SID lysine:ME, g/Mcal	2.62	2.61	2.62
CP, %	16.9	16.9	19.1
Ca, %	0.50	0.50	0.50
P, %	0.39	0.39	0.42
Available P, %	0.13	0.13	0.14

[1] Phase 3 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.018, 0.036, and 0.054% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 16.95, 20.40, and 23.65% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[6] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) at 9.0 g/ton was added.

Table 5. Composition of diets (Exp. 2, Phase 1, 153 to 195 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	58.07	58.07	54.80–48.45
Soybean meal	9.77	9.77	13.23
DDGS[4]	30.00	30.00	30.00
Limestone	1.17	1.17	1.14–1.09
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.535	0.535	0.380–0.080
L-tryptophan	---	0.017	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.79	0.79	0.79
Isoleucine:lysine	65	65	77
Leucine:lysine	190	190	207
Methionine:lysine	33	33	36
Met & Cys:lysine	66	66	73
Threonine:lysine	62	62	72
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	78	78	90
Phenylalanine:lysine	93	93	109
Tyrosine:lysine	68	68	80
Total lysine, %	0.95	0.95	0.96
ME, kcal/lb	1,526	1,527	1,525
SID Lysine:ME, g/Mcal	2.35	2.35	2.32
CP, %	18.0	18.1	20.4
Ca, %	0.50	0.50	0.50
P, %	0.44	0.44	0.47
Available P, %	0.20	0.20	0.21

[1] Phase 1 diet of Exp.1 was fed from 161 to 205 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.

[2] L-tryptophan was added at 0.017, 0.033, and 0.049% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 13.23, 16.58, and 19.93% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.

[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.

[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).

[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 6. Composition of diets (Exp. 2, Phase 2, 195 to 244 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	63.18	63.16	60.54–55.37
Soybean meal	4.70	4.70	7.49
DDGS[4]	30.00	30.00	30.00
Limestone	1.20	1.20	1.18–1.13
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.465	0.465	0.340–0.095
L-tryptophan	---	0.013	---
Phytase[5]	0.01	0.01	0.01
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.64	0.64	0.64
Isoleucine:lysine	68	68	81
Leucine:lysine	219	219	236
Methionine:lysine	38	38	41
Met & Cys:lysine	76	76	82
Threonine:lysine	66	66	77
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	86	86	97
Phenylalanine:lysine	101	101	117
Tyrosine:lysine	72	72	85
Total lysine, %	0.79	0.79	0.80
ME, kcal/lb	1,527	1,527	1,525
SID lysine:ME, g/Mcal	1.90	1.90	1.90
CP, %	16.1	16.1	18.0
Ca, %	0.50	0.50	0.50
P, %	0.42	0.42	0.45
Available P, %	0.20	0.20	0.20

[1] Phase 2 diet of Exp.2 was fed from 195 to 244 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.013, 0.026, and 0.039% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 7.49, 10.17, and 12.96% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 7. Composition of diets (Exp. 2, Phase 3, 244 to 287 lb; as-fed basis)[1]

		Tryptophan source[2]	
Item	Control diet[3]	L-tryptophan	Soybean meal
Ingredient, %			
Corn	66.65	66.63	63.14–56.00
Soybean meal	16.08	16.08	19.87
DDGS[4]	15.00	15.00	15.00
Limestone	1.10	1.10	1.08–1.03
Salt	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09
L-lysine sulfate	0.530	0.530	0.360–0.020
L-threonine	0.100	0.100	0.005–0.00
Methionine hydroxy	0.040	0.040	0.010–0
L-tryptophan	---	0.018	---
Phytase[5]	0.01	0.01	0.01
Ractopamine HCl, 9 g/lb[6]	0.05	0.05	0.05
Total	100	100	100
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.88	0.88	0.88
Isoleucine:lysine	61	61	73
Leucine:lysine	160	160	177
Methionine:lysine	32	32	32
Met & Cys:lysine	61	61	64
Threonine:lysine	68	68	69
Tryptophan:lysine	16.0	18.0–22.0	18.0–22.0
Valine:lysine	71	71	82
Phenylalanine:lysine	84	84	99
Tyrosine:lysine	61	61	73
Total lysine, %	1.01	1.01	1.03
ME, kcal/lb	1,526	1,526	1,524
SID Lysine:ME, g/Mcal	2.62	2.61	2.62
CP, %	17.7	17.7	20.3
Ca, %	0.50	0.50	0.50
P, %	0.40	0.40	0.44
Available P, %	0.13	0.13	0.14

[1] Phase 3 diet of Exp. 1 was fed from 205 to 240 lb. Corn and soybean meal were analyzed for total amino acid content and used in the diet formulation.
[2] L-tryptophan was added at 0.018, 0.036, and 0.054% to the control diet at the expense of corn to provide SID tryptophan:lysine ratios of 18, 20, and 22%. Soybean meal replaced corn and crystalline lysine in the control diet for total soybean meal levels of 19.87, 23.66, and 27.46% to achieve SID tryptophan:lysine ratios of 18, 20, and 22%.
[3] Control diet was formulated to 16% SID tryptophan:lysine ratio.
[4] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[5] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[6] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) at 9.0 g/ton was added.

Table 8. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in diets containing dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs[1]

	Control	L-trp			SBM				Probability, *P*<					
									Trp × source		L-trp[2]		SBM	
	16.0	18.0	20.0	22.0	18.0	20.0	22.0	SEM	Linear	Quad	Linear	Quad	Linear	Quad
Replications	13	12	13	12	12	13	10							
Initial wt, lb	156.9	156.9	156.6	156.9	156.9	157.0	156.8	4.152	0.99	0.92	0.98	0.93	0.99	0.97
Final wt, lb	275.1	276.9	281.2	277.5	279.8	284.7	278.4	8.112	0.78	0.36	0.29	0.26	0.19	0.03
Phase 1[3]														
ADG, lb	1.93	2.01	2.00	1.95	1.94	2.06	2.00	0.038	0.13	0.50	0.73	0.09	0.05	0.39
ADF, lb	5.69	5.54	5.79	5.56	5.59	5.72	5.51	0.103	0.50	0.89	0.73	0.66	0.30	0.54
F/G	2.95	2.76	2.89	2.86	2.90	2.77	2.76	0.071	0.04	0.38	0.56	0.13	0.01	0.69
Phase 2														
ADG, lb	1.87	1.83	1.95	1.92	1.93	2.04	1.91	0.060	0.78	0.02	0.07	0.86	0.16	0.01
ADF, lb	6.30	6.11	6.64	6.65	6.49	6.66	6.49	0.182	0.05	0.01	0.01	0.24	0.07	0.05
F/G	3.37	3.33	3.41	3.47	3.36	3.28	3.41	0.056	0.21	0.75	0.12	0.40	0.86	0.23
Phase 3														
ADG, lb	2.20	2.30	2.44	2.21	2.34	2.38	2.29	0.071	0.67	0.55	0.52	0.01	0.29	0.09
ADF, lb	6.98	6.54	6.94	6.64	7.01	6.92	6.96	0.203	0.46	0.67	0.29	0.57	0.80	0.98
F/G	3.19	2.85	2.88	3.01	3.01	2.92	3.04	0.125	0.94	0.25	0.06	0.01	0.06	0.01
Overall														
ADG, lb	1.98	2.02	2.09	2.00	2.04	2.13	2.04	0.026	0.20	0.70	0.17	0.01	0.01	0.01
ADF, lb	6.24	5.99	6.38	6.22	6.27	6.35	6.25	0.076	0.51	0.20	0.30	0.52	0.78	0.35
F/G	3.16	2.97	3.06	3.11	3.07	2.98	3.06	0.031	0.03	0.30	0.68	0.01	0.01	0.01

continued

Table 8. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in diets containing dried distillers grains with solubles (DDGS) on growth performance and carcass characteristics of finishing pigs[1]

	Control	L-trp			SBM				Probability, P<					
									Trp × source		L-trp[2]		SBM	
	16.0	18.0	20.0	22.0	18.0	20.0	22.0	SEM	Linear	Quad	Linear	Quad	Linear	Quad
Carcass wt, lb	205.2	207.5	209.5	206.3	210.3	211.8	206.3	8.382	0.96	0.31	0.54	0.15	0.59	0.01
Yield, %	74.3	75.4	74.7	75.8	75.8	74.6	74.6	0.608	0.01	0.08	0.01	0.99	0.86	0.03
Backfat, in.[4]	0.58	0.58	0.58	0.57	0.56	0.55	0.56	0.040	0.39	0.22	0.50	0.94	0.12	0.13
Loin depth, in.	2.83	2.73	2.77	2.79	2.78	2.79	2.77	0.021	0.50	0.08	0.35	0.01	0.11	0.42
Lean, %	58.5	58.2	58.4	58.5	58.6	58.8	58.6	0.630	0.70	0.07	0.84	0.24	0.55	0.29

[1] A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen and 10 to 13 pens per treatment.
[2] *P*-value of effect of standardized ileal digestible tryptophan:lysine ratio dosage within each source of tryptophan.
[3] Phases were from d 0 to 20, 20 to 40, and 40 to 56 in Exp. 1 and from d 0 to 21, 21 to 47, and 47 to 68 in Exp. 2.
[4] Backfat, loin depth, and lean percentage were adjusted to a common HCW.

Table 9. Effects of tryptophan sources to increasing standardized ileal digestible (SID) tryptophan:lysine ratio in DDGS on growth performance and carcass characteristics of finishing pigs (main effect of SID tryptophan:lysine ratio)[1]

	SID trp:lys ratio, %					Probability, *P*<	
						SID trp:lys ratio	
	16	18	20	22	SEM	Linear	Quad
Replications	13	24	26	22			
Initial wt, lb	156.9	157.0	157.0	157.0	4.00	0.98	0.97
Final wt, lb	275.1	278.0	283.0	278.0	7.95	0.24	0.18
Phase 1[2]							
ADG, lb	1.93	1.97	2.03	1.98	0.03	0.17	0.10
ADF, lb	5.69	5.56	5.75	5.54	0.09	0.41	0.50
F/G	2.95	2.83	2.83	2.81	0.06	0.05	0.23
Phase 2							
ADG, lb	1.87	1.88	1.99	1.91	0.06	0.06	0.09
ADF, lb	6.30	6.30	6.65	6.57	0.17	0.01	0.58
F/G	3.37	3.35	3.35	3.44	0.04	0.31	0.19
Phase 3							
ADG, lb	2.20	2.32	2.41	2.25	0.06	0.30	0.01
ADF, lb	6.98	6.78	6.93	6.80	0.18	0.44	0.71
F/G	3.19	2.93	2.90	3.03	0.12	0.03	0.01
Overall							
ADG, lb	1.98	2.03	2.11	2.02	0.02	0.02	0.01
ADF, lb	6.24	6.13	6.37	6.23	0.06	0.44	0.84
F/G	3.16	3.02	3.02	3.09	0.02	0.06	0.01
Carcass wt, lb	205.2	208.9	210.7	206.3	8.28	0.50	0.01
Yield, %	74.3	75.6	74.7	75.2	0.57	0.15	0.16
Backfat, in.[3]	0.58	0.57	0.57	0.57	0.04	0.19	0.30
Loin depth, in.	2.83	2.75	2.78	2.78	0.02	0.13	0.02
Lean, %	58.5	58.4	58.6	58.5	0.62	0.63	0.97

[1] A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen. There were 13 pens per control treatment and 22 to 26 pens for main effect of 18 to 22 SID tryptophan:lysine ratio.

[2] Phases were from d 0 to 20, d 20 to 40, and d 40 to 56 in Exp. 1 and from d 0 to 21, d 21 to 47, and d 47 to 68 in Exp. 2.

[3] Backfat, loin depth, and lean percentage were adjusted to a common HCW.

Table 10. Effects of tryptophan sources to increasing standardized ileal digestible tryptophan:lysine ratio in DDGS on growth performance and carcass characteristics of finishing pigs (main effect of tryptophan source)[1]

	Tryptophan source			
	L-trp	SBM	SEM	Probability, *P*<
Replications	37	35		
Initial wt, lb	157.0	157.0	3.93	0.95
Final wt, lb	278.0	281.0	7.87	0.36
Phase 1[2]				
ADG, lb	1.99	2.00	0.02	0.67
ADF, lb	5.63	5.60	0.08	0.73
F/G	2.84	2.81	0.05	0.55
Phase 2				
ADG, lb	1.90	1.96	0.05	0.03
ADF, lb	6.46	6.54	0.17	0.26
F/G	3.41	3.35	0.03	0.25
Phase 3				
ADG, lb	2.32	2.34	0.05	0.74
ADF, lb	6.71	6.96	0.17	0.02
F/G	2.91	2.99	0.12	0.11
Overall				
ADG, lb	2.04	2.07	0.02	0.07
ADF, lb	6.20	6.29	0.05	0.12
F/G	3.05	3.04	0.02	0.70
Carcass wt, lb	207.8	209.5	8.23	0.30
Yield, %	75.3	75.0	0.55	0.23
Backfat, in.[3]	0.58	0.56	0.04	0.04
Loin depth in.	2.76	2.78	0.01	0.23
Lean, %	58.3	58.6	0.62	0.02

[1]A total of 2,290 pigs (PIC 1050 × 337; initially 157 lb) were used in 2 replicated studies with 26 to 28 gilts per pen with 35 to 37 pens per main effect of tryptophan source.
[2]Phases were from d 0 to 20, d 20 to 40, and d 40 to 56 in Exp. 1 and from d 0 to 21, d 21 to 47, and d 47 to 68 in Exp. 2.
[3]Backfat, loin depth, and lean percentage were adjusted to a common HCW.

Effects of Lowering Dried Distillers Grains with Solubles and Wheat Middlings with or without the Addition of Choice White Grease Prior to Marketing on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality, and Intestinal Weights[1]

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Summary

A total of 225 pigs (PIC 327 × 1050, initially 100.1 lb) were used in a 92-d study to determine the effects of withdrawing high-fiber diets 19 d before market on growth performance, carcass characteristics, fat quality, and intestinal weights of finishing pigs. Pigs were allotted to 1 of 7 dietary treatments (5 or 6 pens/treatment). Treatments were arranged in a 2 × 3 factorial plus control with main effects of added choice white grease (CWG; 0 or 3%) during the withdrawal period (d 73 to 92) and fiber levels of low (corn-soybean meal diet), medium (9.5% wheat middlings [midds] and 15% dried distillers grains with solubles [DDGS]), or high (19% midds and 30% DDGS) during the withdrawal period. Pigs were fed high-fiber (19% midds and 30% DDGS) diets from d 0 to 73. Control pigs were fed low-fiber corn-soybean meal diets from d 0 to 92. No CWG × fiber interactions ($P > 0.13$) occurred except for jowl iodine value (IV), which increased (linear, $P < 0.03$) with increasing DDGS and midds only when CWG was added to the diet during the withdrawal period. Adding CWG during the withdrawal period (d 73 to 92) improved ($P < 0.02$) ADG (1.81 vs 1.94 lb/d) and F/G (3.46 vs 3.19), leading to an overall (d 0 to 92) improvement ($P < 0.02$) in F/G. Carcass yield and backfat depth increased (linear, $P < 0.05$) when low-fiber diets were fed from d 73 to 92. Pigs fed high levels of DDGS and midds had increased ($P < 0.001$) jowl IV, with a larger increase when CWG was added. Feeding low levels of DDGS and midds during the withdrawal period decreased (linear, $P < 0.01$) whole intestine weights, mainly due to the reduction ($P < 0.02$) in rinsed stomach and full large-intestine weights. Lowering dietary DDGS and midds during a 19-d withdrawal period increased yield through reduced large intestine weight and content and lowered jowl IV. The addition of CWG improved F/G but did not improve carcass characteristics.

Key words: DDGS, fiber, finishing pig, NDF, wheat middlings, withdrawal

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Introduction

Feed ingredients such as wheat midds and DDGS are often used as alternatives to corn and soybean meal in swine diets. Although these ingredients are used to lower feed costs, they have been shown to affect performance and carcass characteristics negatively. Two areas of concern are the reduction in carcass yield with pigs fed high-fiber diets and the negative effect of DDGS on fat quality. Soft carcass fat with a high IV has been observed consistently in pigs fed high levels of DDGS. Reducing the level of DDGS in the diet prior to market has been successful in lowering IV and improving yield, but little is known about including CWG in the diet during withdrawal or its potential effects on yield, carcass characteristics, and carcass fat quality. More data are also required to determine why yield is reduced when feeding diets containing high-fiber ingredients such as DDGS or midds.

The objective of this trial was to determine the effects of decreasing or withdrawing fiber sources and including CWG prior to market on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (8 ft × 10 ft). The pens had adjustable gates facing the alleyway, allowing 10 ft^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A total of 225 pigs (PIC 327 × 1050, initially 100.1 lb) were used in a 92-d trial. Pens of pigs (4 gilts and 2 barrows per pen or 4 gilts and 3 barrows per pen) were randomly allotted by initial weight to 1 of 7 dietary treatments with 5 or 6 replications per treatment. Treatments were arranged in a 2 × 3 factorial plus control with the main effects of added CWG (0 or 3%) during the withdrawal period (d 73 to 92) and fiber levels of low (corn-soybean meal diet), medium (9.5% midds and 15% DDGS), or high (19% midds and 30% DDGS) during the withdrawal period. Pigs were fed high-fiber (19% midds and 30% DDGS) diets from d 0 to 73. Control pigs were fed low-fiber corn-soybean meal diets from d 0 to 92. Dietary treatments were corn-soybean meal–based and fed in 4 phases (Tables 1 and 2). All diets were fed in meal form.

Midds and DDGS samples were collected at the time of feed manufacturing and a composite sample was analyzed (Table 3). Feed samples were collected from every feeder during each phase and combined for a single composite sample by treatment to measure bulk density (Table 4).

Pigs and feeders were weighed approximately every 3 wk to calculate ADG, ADFI, and F/G. On d 92, all pigs were weighed individually. The second heaviest gilt in each pen

(1 pig per pen, 5 pigs per treatment) was identified for harvest at the K-State Meats Lab (KSU); all others were then transported to Triumph Foods LLC, St. Joseph, MO. The pigs selected for harvest at KSU were blocked by treatment and randomly allotted to a harvest order to equalize the withdrawal time from feed before slaughter. Hot carcass weights were measured immediately after evisceration. Following evisceration, the entire pluck (heart, lungs, liver, kidneys, spleen, stomach, cecum, large intestine, small intestine, and reproductive tract) was weighed and then the individual organs were weighed. After full organ weights were recorded, the large intestine, stomach, and cecum were physically stripped of contents and reweighed, then flushed with water, physically stripped of contents, and weighed again. Pigs harvested at the commercial packing plant were individually and sequentially tattooed with a unique number to allow for carcass data collection at the packing plant and individual data retrieval. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, backfat, loin depth, and percentage lean. Because HCW differed among treatments, it was used as a covariate for backfat, loin depth, and percentage lean. Also, jowl fat samples were collected and analyzed by Near Infrared Spectroscopy at the plant for IV. Percentage yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of fiber level and CWG prior to market were tested. Linear and quadratic contrasts were used to determine the effects of withdrawal fiber levels. Differences between treatments were determined by using least squares means. Results were considered significant at $P \le 0.05$ and considered a trend at $P \le 0.10$.

Results and Discussion

Bulk density tests showed that adding dietary fiber from midds and DDGS dramatically decreased diet bulk density (Table 4).

Overall, (d 0 to 92) the withdrawal treatments did not influence ($P > 0.39$) ADG; however, adding CWG to the diet during the withdrawal period (d 73 to 92) increased ($P < 0.02$) ADG and improved ($P < 0.006$) F/G, resulting in an overall (d 0 to 92) improvement ($P < 0.002$) in feed efficiency (Tables 5 and 6). Feeding high-fiber diets during the first 73 d had no impact ($P > 0.44$) on ADG; however, the pigs fed higher-fiber diets tended ($P < 0.10$) to have poorer feed efficiency than pigs fed the low-fiber (control) diet.

For carcass traits and fat quality, there were no CWG × fiber interactions ($P < 0.13$) except for jowl IV, which increased (linear, $P < 0.03$) with increasing DDGS and midds only when CWG was added to the diet during the withdrawal period (Tables 7 and 8). Carcass yield and backfat depth increased (linear, $P < 0.05$) when low-fiber diets were fed from d 73 to 92. Pigs fed high DDGS and midds had increased ($P < 0.001$) jowl IV, with a larger increase when CWG was added.

For intestinal measurements, the fiber level fed during the withdrawal period had minor effects on most organ weights except the digestive tract, which, as expected, was the most influenced by fiber levels. Feeding low levels of DDGS and midds during the withdrawal period decreased (linear, $P < 0.01$) whole intestine weights whether calculated on a weight basis (Tables 9 and 10) or percentage of live weight basis (Tables 11 and 12). Cecum weights were not influenced ($P > 0.24$) by the addition of CWG during the withdrawal; however, minor ($P < 0.11$) reductions were observed in full cecum weights when the low-fiber diet was fed during the withdrawal period. These differences were not maintained in stripped or rinsed cecum weights, which indicates that the change was due to an increase in fill rather than an increase in actual organ weight. The greatest impact of withdrawal treatments was on large intestine weight and rinsed stomach weights with the similar response to the yield response. Reducing fiber level during the 19-d withdrawal reduced ($P < 0.01$) full large intestine weight, with a greater response when CWG was added to the diet, resulting in a tendency ($P > 0.09$) for an interactive effect. Similar to the cecum, the response in the large intestine was due to fill. After the large intestine was stripped and rinsed, the fiber level fed had no impact ($P > 0.21$) on the actual intestine weight. Although no significant differences ($P > 0.18$) were detected in full stomach weights, rinsed stomach weights tended ($P < 0.06$) to be reduced when calculated on a weight basis and were reduced ($P < 0.02$) when calculated as a percentage of BW when low-fiber diets were fed during the withdrawal, indicating a reduction in actual organ size.

In summary, withdrawing pigs from a high-fiber diet containing DDGS and midds during a 19-d withdrawal period increased carcass yield through reduced large intestine content and rinsed stomach weight and improved jowl IV. The addition of CWG improved F/G but worsened jowl IV and did not improve carcass characteristics.

Table 1. Phase 1, 2, and 3 diet composition (as-fed basis)[1]

		Phase 1		Phase 2		Phase 3	
	NDF, %:	9.2	18.9	9.3	19.0	9.3	19.0
	ADF, %:	3.3	6.7	3.2	6.6	3.1	6.5
	Wheat midds, %:	0	19	0	19	0	19
Item	DDGS, %:[2]	0	30	0	30	0	30
Ingredient, %							
Corn		73.70	34.90	78.95	40.00	82.65	43.55
Soybean meal (46.5% CP)		23.80	13.75	18.85	8.70	15.30	5.20
DDGS		---	30.00	---	30.00	---	30.00
Wheat midds		---	19.00	---	19.00	---	19.00
Monocalcium P, (21% P)		0.45	---	0.35	---	0.25	---
Limestone		1.05	1.30	1.00	1.28	0.98	1.29
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix		0.15	0.15	0.13	0.13	0.10	0.10
Trace mineral premix		0.15	0.15	0.13	0.13	0.10	0.10
L-lysine HCl		0.17	0.31	0.15	0.29	0.14	0.28
DL-methionine		0.02	---	---	---	---	---
L-threonine		0.03	---	0.01	---	---	---
Phytase[3]		0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0
Crude fiber, %		2.5	4.9	2.5	4.9	2.4	4.8
Standardized ileal digestible (SID) amino acids, %							
Lysine		0.93	0.93	0.79	0.79	0.69	0.69
Isoleucine:lysine		69	72	70	74	72	76
Leucine:lysine		156	188	169	206	181	224
Methionine:lysine		30	34	30	37	32	40
Met & Cys:lysine		59	70	62	77	66	83
Threonine:lysine		63	66	63	69	64	72
Tryptophan:lysine		19	19	19	19	19	19
Valine:lysine		78	88	81	94	85	99
SID lysine:ME/Mcal		2.79	2.84	2.36	2.41	2.06	2.10
ME, kcal/lb		1,513	1,484	1,516	1,486	1,520	1,487
Total lysine, %		1.04	1.09	0.89	0.94	0.78	0.83
CP, %		17.52	20.83	15.62	18.91	14.28	17.57
Ca, %		0.59	0.58	0.53	0.56	0.49	0.55
P, %		0.47	0.58	0.42	0.56	0.39	0.55
Available P, %		0.27	0.39	0.25	0.38	0.22	0.38

[1] Phase 1 diets were fed from approximately 100 to 130 lb; Phase 2 diets were fed from 130 to 180 lb; Phase 3 were fed from 180 to 230 lb.
[2] DDGS: dried distillers grain with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided per pound of diet: 353.8 phytase units (FTU)/lb and 0.11% available P released.

Table 2. Phase 4 diet composition (as-fed basis)[1]

NDF, %:	9.3	9.3	14.2	19.0	9.0	14.0	18.7
ADF, %:	3.1	3.1	4.8	6.4	3.0	4.7	6.4
Wheat midds, %:	0	0	15	30	0	15	30
DDGS, %:[2]	0	0	9.5	19	0	9.5	19
Item Choice white grease, %:	0	0	0	0	3	3	3
Ingredient, %							
Corn	84.95	84.95	65.60	45.80	80.65	61.25	41.45
Soybean meal (46.5% CP)	13.15	13.15	8.05	3.05	14.45	9.35	4.35
DDGS	---	---	15.00	30.00	---	15.00	30.00
Wheat midds	---	---	9.50	19.00	---	9.50	19.00
Monocalcium P, (21% P)	0.20	0.20	---	---	0.20	---	---
Limestone	0.93	0.93	1.05	1.28	0.93	1.05	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Choice white grease	---	---	---	---	3.00	3.00	3.00
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08
L-lysine HCl	0.13	0.13	0.20	0.27	0.13	0.20	0.27
Phytase[3]	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Crude fiber, %	2.4	2.4	3.6	4.8	2.3	3.5	4.7
Standardized ileal digestible (SID) amino acids, %							
Lysine	0.63	0.63	0.63	0.63	0.66	0.66	0.66
Isoleucine:lysine	73	73	75	78	72	75	77
Leucine:lysine	191	191	214	238	184	206	228
Methionine:lysine	33	33	38	43	32	37	41
Met & Cys:lysine	69	69	78	88	66	76	85
Threonine:lysine	66	66	70	74	65	69	73
Tryptophan:lysine	19	19	19	19	19	19	19
Valine:lysine	87	87	95	103	86	93	100
SID lysine:ME/Mcal	1.88	1.88	1.90	1.92	1.88	1.90	1.92
ME, kcal/lb	1,522	1,522	1,508	1,488	1,584	1,569	1,550
Total lysine, %	0.72	0.72	0.74	0.77	0.75	0.77	0.79
CP, %	13.46	13.46	15.1	16.75	13.70	15.34	16.99
Ca, %	0.46	0.46	0.46	0.54	0.46	0.47	0.54
P, %	0.37	0.37	0.43	0.54	0.37	0.43	0.54
Available P, %	0.21	0.21	0.27	0.37	0.21	0.27	0.37

[1] Phase 4 diets were fed from approximately 230 to 280 lb.
[2] DDGS: dried distillers grain with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided per pound of diet: 353.8 phytase units (FTU)/lb and 0.11% available P released.

Table 3. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (midds), as-fed basis

Nutrient, %	DDGS	Midds
DM	90.97	89.39
CP	27.2 (27.2)[1]	15.5 (15.9)
Fat (oil)	11.5	3.3
Crude fiber	9.1 (7.7)	8.1 (7.0)
ADF	12.4 (9.9)	10.5 (10.7)
NDF	31.1 (25.3)	32.1 (35.6)
Ash	4.22	5.68

[1] Values in parentheses indicate those used in diet formulation.

Table 4. Bulk density of experimental diets (as-fed basis)

	Treatments						
NDF, %:	9.3	9.3	14.2	19.0	9.0	14.0	18.7
Wheat midds, %:	0	0	15	30	0	15	30
DDGS[1], %:	0	0	9.5	19	0	9.5	19
Bulk density, lb/bu[2,3] CWG,[4] %:	0	0	0	0	3	3	3
Phase 1	53.3	---	---	40.6	---	---	---
Phase 2	52.7	---	---	39.1	---	---	---
Phase 3	50.0	---	---	37.0	---	---	---
Phase 4	50.8	50.8	43.2	36.5	49.7	43.3	37.5

[1] DDGS: dried distillers grains with solubles.
[2] Diet samples collected from the top of each feeder during each phase.
[3] Phase 1 was d 0 to 23; Phase 2 was d 23 to 43; Phase 3 was d 43 to 73; Phase 4 was d 73 to 92.
[4] CWG: choice white grease.

Table 5. Effect of dietary NDF and added fat prior to marketing on growth performance[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% added fat			
d 73 to 90:	Low	Low	Med[4]	High	Low	Med	High	SEM
Weight, lb								
d 0	101.0	101.1	101.2	101.1	101.1	101.0	101.1	1.98
d 23	146.8	146.3	145.7	147.8	146.6	146.0	146.3	2.10
d 43	179.3	179.9	180.0	179.9	178.9	180.0	179.8	2.57
d 73	238.7	237.1	237.2	236.9	237.3	237.7	236.9	3.04
d 92	273.8	270.5	272.4	272.8	274.7	274.5	273.8	3.30
d 0 to 73								
ADG, lb	1.89	1.86	1.86	1.86	1.87	1.84	1.86	0.03
ADFI, lb	5.29	5.37	5.42	5.38	5.29	5.34	5.25	0.13
F/G	2.80	2.88	2.91	2.89	2.83	2.91	2.83	0.04
d 73 to 92								
ADG, lb	1.85	1.76	1.85	1.80	1.96	1.94	1.94	0.07
ADFI, lb	6.17	6.26	6.39	6.12	6.35	6.15	6.07	0.15
F/G	3.35	3.58	3.48	3.40	3.24	3.19	3.15	0.11
d 0 to 92								
ADG, lb	1.88	1.84	1.86	1.85	1.89	1.86	1.88	0.03
ADFI, lb	5.47	5.56	5.62	5.53	5.51	5.50	5.42	0.12
F/G	2.91	3.02	3.02	2.99	2.92	2.96	2.89	0.04

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 101.1 lb) were used in this 92-d study.
[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% midds with NDF of 9.3%.
[3] Refers to diet with 30% DDGS and 19.0% midds with NDF of 19.0%.
[4] Refers to diet with 15% DDGS and 9.5% midds with NDF of 14.2%.

Table 6. Effect of dietary NDF and added fat prior to marketing on growth performance[1]

	Probability, *P*<								
		Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with 3% fat[6]	
	Fat[2]	Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Weight, lb									
d 0	0.97	0.99	1.00	0.99	0.95	1.00	0.97	0.99	0.96
d 23	0.87	0.80	0.65	0.70	0.82	0.65	0.63	0.92	0.88
d 43	0.86	0.87	0.87	0.87	0.90	1.00	0.98	0.81	0.84
d 73	0.92	0.93	0.90	0.97	0.95	0.97	0.97	0.93	0.90
d 92	0.42	0.85	0.86	0.66	0.94	0.66	0.86	0.86	0.94
d 0 to 73									
ADG, lb	0.79	0.90	0.69	0.95	0.68	0.97	0.99	0.89	0.57
ADFI, lb	0.39	0.93	0.62	0.87	0.91	0.96	0.79	0.86	0.67
F/G	0.26	0.97	0.18	0.82	0.43	0.85	0.69	0.89	0.13
d 73 to 92									
ADG, lb	0.02	0.92	0.61	0.65	0.50	0.70	0.40	0.80	0.91
ADFI, lb	0.64	0.22	0.62	0.67	0.37	0.56	0.33	0.24	0.78
F/G	0.006	0.29	0.97	0.75	0.96	0.33	0.95	0.60	0.99
d 0 to 92									
ADG, lb	0.39	0.95	0.87	0.78	0.45	0.88	0.67	0.81	0.52
ADFI, lb	0.39	0.68	0.61	0.81	0.86	0.90	0.63	0.64	0.81
F/G	0.02	0.54	0.31	0.95	0.54	0.70	0.78	0.63	0.25

[1] A total of 225 pigs (PIC 327 × 1050, initial BW=101.1 lb) were used in a 92-d study.
[2] Main effect of fat regardless of fiber level (Treatments 2, 3, and 4 vs. 5, 6, and 7).
[3] Main effect of fiber regardless of fat inclusion (Treatments 2, 3, 4 and 5, 6, 7).
[4] Interaction effect of fat × fiber (Treatments 2, 3, 4 and 5, 6, 7).
[5] Effect of fiber level on diets without fat (Treatments 2, 3, 4).
[6] Effect of fiber level on diets with fat (Treatments 5, 6, 7).

Table 7. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, %[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% added fat			
d 73 to 92:	Low	Low	Med[4]	High	Low	Med	High	SEM
Carcass yield[5]	72.6	72.6	71.8	71.9	73.0	72.3	71.5	0.31
HCW, lb	199.3	196.7	195.7	196.2	200.6	199.4	195.6	2.93
Backfat depth, in.[6]	0.75	0.69	0.67	0.67	0.73	0.70	0.65	0.02
Loin depth, in.[6]	2.29	2.21	2.24	2.27	2.32	2.16	2.23	0.04
Lean, %[6]	52.8	53.0	53.3	53.4	53.0	52.6	53.4	0.30
Jowl iodine value	69.4	77.8	78.5	79.2	77.3	78.6	81.2	0.50

[1] A total of 225 pigs (PIC 327 × 1050, initial BW = 101.1 lb) were used in a 92-d study.
[2] Refers to a diet with 0% dried distillers grains with solubles (DDGS) and 0% midds with NDF of 9.3%.
[3] Refers to a diet with 30% DDGS and 19.0% midds with NDF of 19.0%.
[4] Refers to a diet with 15% DDGS and 9.5% midds with NDF of 14.2%.
[5] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[6] Carcass characteristics other than yield and iodine value were adjusted by using HCW as a covariate.

Table 8. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig carcass characteristics[1]

	Probability, $P<$								
	Fat[2]	Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]	
		Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Carcass yield, %[5]	0.50	0.003	0.53	0.23	0.44	0.16	0.32	0.003	0.91
HCW, lb	0.38	0.40	0.91	0.49	0.72	0.91	0.86	0.28	0.74
Backfat depth, in.[6]	0.40	0.05	0.92	0.22	0.73	0.59	0.75	0.03	0.86
Loin depth, in.[6]	0.91	0.74	0.13	0.15	0.16	0.42	0.94	0.21	0.04
Lean, %[6]	0.48	0.23	0.38	0.95	0.22	0.42	0.80	0.38	0.14
Jowl iodine value	0.24	< 0.001	0.54	0.03	0.46	0.09	0.93	< 0.001	0.35

[1] A total of 225 pigs (PIC 327 × 1050, initial BW=101.1 lb) were used in a 92-d study.
[2] Main effect of fat regardless of fiber level (Treatments 2, 3, and 4 vs. 5, 6, and 7).
[3] Main effect of fiber regardless of fat inclusion (Treatments 2, 3, 4 and 5, 6, 7).
[4] Interaction effect of fat × fiber (Treatments 2, 3, 4 and 5, 6, 7).
[5] Effect of fiber level on diets without fat (Treatments 2, 3, 4).
[6] Effect of fiber level on diets with fat (Treatments 5, 6, 7).

Table 9. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, lb[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% added fat			
d 73 to 92	Low	Low	Med[4]	High	Low	Med	High	SEM
Full pluck	30.81	29.35	30.17	31.48	29.19	28.80	32.50	1.14
Whole intestine	19.73	18.01	19.07	19.98	17.62	18.39	21.36	0.93
Stomach								
Full	2.64	2.15	2.00	2.66	2.24	2.14	2.47	0.24
Stripped	1.51	1.44	1.51	1.60	1.53	1.50	1.66	0.07
Rinsed	1.52	1.40	1.49	1.54	1.52	1.47	1.65	0.06
Cecum								
Full	2.22	1.44	1.73	1.84	1.65	1.45	1.81	0.14
Stripped	0.68	0.59	0.60	0.63	0.68	0.60	0.65	0.03
Rinsed	0.63	0.56	0.57	0.59	0.65	0.58	0.59	0.04
Large intestine								
Full	7.71	7.74	8.55	8.48	7.14	8.38	10.46	0.65
Stripped	3.53	3.68	3.82	3.70	3.56	3.99	4.18	0.21
Rinsed	3.44	3.44	3.61	3.44	3.49	3.55	3.84	0.18
Small intestine								
Full	6.43	6.09	5.59	6.05	6.01	5.88	6.06	0.25
Heart	0.98	0.97	0.91	0.91	0.90	0.95	0.89	0.04
Lungs	2.17	2.22	2.18	2.29	2.12	2.25	2.22	0.09
Liver	4.53	4.60	4.55	4.50	4.35	4.17	4.46	0.16
Kidneys	0.89	0.88	0.91	0.85	0.88	0.83	0.87	0.04
Spleen	0.52	0.53	0.50	0.51	0.50	0.50	0.50	0.04
Reproductive tract	1.54	1.70	1.70	1.99	2.21	1.32	1.84	0.26

[1] A total of 225 pigs (PIC 327 × 1050, initial BW = 101.1 lb) were used in a 92-d study.
[2] Refers to a diet with 0% dried distillers grains with solubles (DDGS) and 0% midds with NDF of 9.3%.
[3] Refers to a diet with 30% DDGS and 19.0% midds with NDF of 19.0%.
[4] Refers to a diet with 15% DDGS and 9.5% midds with NDF of 14.2%.

Table 10. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, lb[1]

	Probability, *P*<								
	Fat[2]	Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]	
		Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Full pluck	0.87	0.04	0.30	0.64	0.41	0.24	0.87	0.07	0.19
Whole intestine	0.90	0.01	0.57	0.39	0.51	0.18	0.95	0.01	0.39
Stomach									
Full	0.95	0.18	0.19	0.61	0.68	0.20	0.22	0.54	0.51
Stripped	0.44	0.06	0.41	0.84	0.50	0.15	0.91	0.21	0.29
Rinsed	0.22	0.06	0.43	0.94	0.27	0.16	0.81	0.19	0.18
Cecum									
Full	0.81	0.11	0.50	0.49	0.20	0.09	0.65	0.52	0.17
Stripped	0.24	0.90	0.26	0.36	0.41	0.46	0.83	0.58	0.17
Rinsed	0.30	0.70	0.51	0.25	0.60	0.59	0.92	0.28	0.40
Large intestine									
Full	0.51	0.01	0.99	0.09	0.51	0.50	0.65	0.003	0.63
Stripped	0.35	0.17	0.53	0.20	0.98	0.95	0.64	0.06	0.67
Rinsed	0.42	0.38	0.87	0.38	0.41	1.00	0.48	0.21	0.63
Small intestine									
Full	0.75	0.99	0.19	0.87	0.50	0.92	0.16	0.90	0.65
Heart	0.61	0.38	0.72	0.53	0.22	0.29	0.54	0.86	0.26
Lungs	0.69	0.40	0.98	0.88	0.38	0.63	0.55	0.49	0.52
Liver	0.14	0.98	0.46	0.56	0.46	0.70	1.00	0.67	0.30
Kidneys	0.62	0.69	1.00	0.84	0.30	0.67	0.46	0.89	0.46
Spleen	0.69	0.80	0.78	0.80	0.78	0.73	0.69	1.00	1.00
Reproductive tract	0.98	0.89	0.09	0.25	0.26	0.47	0.68	0.36	0.05

[1] A total of 225 pigs (PIC 327 × 1050, initial BW=101.1 lb) were used in a 92-d study.
[2] Main effect of fat regardless of fiber level (Treatments 2, 3, and 4 vs. 5, 6, and 7).
[3] Main effect of fiber regardless of fat inclusion (Treatments 2, 3, 4 and 5, 6, 7).
[4] Interaction effect of fat × fiber (Treatments 2, 3, 4 and 5, 6, 7).
[5] Effect of fiber level on diets without fat (Treatments 2, 3, 4).
[6] Effect of fiber level on diets with fat (Treatments 5, 6, 7).

Table 11. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, %[1,2]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[3]	High[4]	High	High	High	High	High	
					3% added fat			
d 73to 92:	Low	Low	Med[5]	High	Low	Med	High	SEM
Full pluck	10.98	10.61	10.96	11.69	10.51	10.52	11.74	0.42
Whole intestine	7.03	6.51	6.93	7.42	6.35	6.72	7.73	0.35
Stomach								
Full	0.94	0.78	0.72	0.99	0.81	0.78	0.90	0.09
Stripped	0.54	0.52	0.55	0.59	0.55	0.55	0.60	0.02
Rinsed	0.54	0.51	0.54	0.57	0.55	0.54	0.60	0.02
Cecum								
Full	0.79	0.52	0.63	0.68	0.60	0.53	0.65	0.06
Stripped	0.24	0.21	0.22	0.23	0.24	0.22	0.23	0.01
Rinsed	0.22	0.20	0.21	0.22	0.23	0.21	0.21	0.01
Large intestine								
Full	2.75	2.80	3.21	3.12	2.58	3.06	3.79	0.25
Stripped	1.26	1.33	1.39	1.37	1.28	1.46	1.51	0.07
Rinsed	1.22	1.24	1.31	1.28	1.26	1.30	1.39	0.06
Small intestine								
Full	2.29	2.20	2.03	2.24	2.16	2.14	2.18	0.08
Heart	0.35	0.35	0.33	0.34	0.32	0.35	0.32	0.01
Lungs	0.77	0.80	0.79	0.85	0.77	0.82	0.80	0.04
Liver	1.61	1.66	1.65	1.67	1.57	1.52	1.61	0.06
Kidneys	0.32	0.32	0.33	0.32	0.32	0.30	0.31	0.01
Spleen	0.18	0.19	0.18	0.19	0.18	0.18	0.18	0.01
Reproductive tract	0.55	0.61	0.62	0.74	0.78	0.49	0.66	0.09

[1] A total of 225 pigs (PIC 327 × 1050, initial BW = 101.1 lb) were used in a 92-d study.
[2] All values are a percent of live weight (ex. (reproductive tract/live weight) × 100).
[3] Refers to a diet with 0% dried distillers grains with solubles (DDGS) and 0% midds with NDF of 9.3%.
[4] Refers to a diet with 30% DDGS and 19.0% midds with NDF of 19.0%.
[5] Refers to a diet with 15% DDGS and 9.5% midds with NDF of 14.2%.

Table 12. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, %[1]

	Probability, *P*<								
		Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]	
	Fat[2]	Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Full pluck	0.66	0.02	0.32	0.87	0.61	0.11	0.73	0.07	0.29
Whole intestine	0.94	0.006	0.60	0.55	0.67	0.11	0.94	0.02	0.50
Stomach									
Full	0.98	0.15	0.19	0.56	0.58	0.16	0.19	0.51	0.59
Stripped	0.52	0.02	0.39	0.63	0.78	0.05	0.68	0.16	0.42
Rinsed	0.24	0.02	0.41	0.73	0.44	0.05	0.96	0.13	0.26
Cecum									
Full	0.73	0.12	0.57	0.40	0.28	0.08	0.70	0.62	0.25
Stripped	0.33	0.74	0.26	0.22	0.52	0.27	0.73	0.53	0.22
Rinsed	0.40	0.85	0.51	0.16	0.71	0.39	0.83	0.26	0.47
Large intestine									
Full	0.68	0.01	0.79	0.13	0.46	0.43	0.50	0.004	0.72
Stripped	0.43	0.10	0.50	0.25	0.84	0.71	0.74	0.05	0.54
Rinsed	0.53	0.25	0.81	0.49	0.55	0.74	0.56	0.19	0.80
Small intestine									
Full	0.97	0.71	0.13	0.91	0.26	0.73	0.07	0.86	0.77
Heart	0.38	0.46	0.64	0.69	0.06	0.42	0.30	0.81	0.09
Lungs	0.62	0.33	0.99	0.85	0.27	0.41	0.43	0.58	0.44
Liver	0.08	0.71	0.43	0.80	0.66	0.93	0.81	0.66	0.39
Kidneys	0.39	0.80	0.99	0.98	0.34	0.88	0.49	0.84	0.51
Spleen	0.63	0.91	0.74	0.95	0.66	0.90	0.58	0.97	0.94
Reproductive tract	0.86	1.00	0.11	0.22	0.31	0.39	0.67	0.39	0.07

[1] A total of 225 pigs (PIC 327 × 1050, initial BW=101.1 lb) were used in a 92-d study.
[2] Main effect of fat regardless of fiber level (Treatments 2, 3, and 4 vs. 5, 6, and 7).
[3] Main effect of fiber regardless of fat inclusion (Treatments 2, 3, 4 and 5, 6, 7).
[4] Interaction effect of fat × fiber (Treatments 2, 3, 4 and 5, 6, 7).
[5] Effect of fiber level on diets without fat (Treatments 2, 3, 4).
[6] Effect of fiber level on diets with fat (Treatments 5, 6, 7).

The Effects of Immunocastration and Dried Distillers Grains with Solubles Withdrawal on Growth Performance, Carcass Characteristics, Fatty Acid Analysis, and Iodine Value of Pork Fat Depots[1]

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Summary

A total of 1,360 pigs (PIC 337 × 1050, initially 53.0 lb) were used in a 125-d study to determine the effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration (IC; Improvest, Pfizer Animal Health, Kalamazoo, MI) on growth performance and carcass fat quality of growing-finishing pigs. Pens of pigs were randomly allotted by initial weight and gender (barrows or IC) to 1 of 3 dietary treatments with 8 replications per treatment for a total of 48 pens with 27 to 29 pigs per pen. Treatments were arranged in a 2 × 3 factorial with the main effects of gender (barrow or IC) and diet (0% DDGS throughout, 30% DDGS throughout, or 30% DDGS through d 75 then withdrawn to 0% to d 125). Boars were injected with Improvest on d 39 and 74 of the study. Dietary treatments were corn-soybean meal–based diets and fed in 5 phases. No gender × diet interactions ($P > 0.18$) were observed except for a tendency for F/G ($P < 0.07$) during the second phase (d 25 to 53), when 1 of the 2 barrow groups fed 30% DDGS had an increase in ADFI resulting in poorer F/G. For the entire period before the second Improvest injection (d 0 to 74), barrows tended ($P < 0.08$) to have increased ADG (1.98 vs. 1.95 lb) and increased ($P < 0.001$) ADFI (4.32 vs. 3.91 lb) but were less efficient ($P < 0.001$) than boars (2.19 vs. 2.01). During the same time period, pigs fed 30% DDGS had reduced ($P < 0.002$) ADG and poorer feed efficiency.

For the period after the second Improvest injection until the first marketing event (d 74 to 107; 33 d after the second dose), IC pigs had increased ($P < 0.01$) ADG (2.29 vs. 2.10 lb), similar ADFI (6.92 vs. 6.81 lb), and were more efficient ($P < 0.001$; 3.02 vs. 3.25) than barrows. From d 0 to 107, IC pigs had improved ($P < 0.03$) ADG (2.05 vs. 2.01 lb), F/G (2.34 vs. 2.52), and lower ADFI (4.80 vs. 5.06 lb) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender did not influence ADG or ADFI but did worsen ($P < 0.001$) feed efficiency.

For the period after the second Improvest injection to the end of the trial (d 74 to 125; 51 d after the second dose), IC pigs had increased ($P < 0.01$) ADG (2.29 vs. 2.10),

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ADFI (7.09 vs. 6.82), and were more efficient (3.09 vs. 3.25) than barrows. Overall (d 0 to 125), IC pigs had improved ($P < 0.003$) ADG (2.07 vs 2.02) and F/G (2.44 vs. 2.58) and lower ADFI (5.05 vs. 5.22) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender again did not influence ADG or ADFI but worsened ($P < 0.001$) feed efficiency.

Carcass yield was lower ($P < 0.001$) for IC pigs than barrows regardless of dietary DDGS or withdrawal strategy. Pigs fed 30% DDGS throughout had decreased ($P < 0.001$) carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss, returning values similar to that of pigs fed the control diet throughout. Carcass fat iodine values (IV) were consistently higher ($P < 0.001$) regardless of fat depot or harvest time when 30% DDGS were included in the diet. The withdrawal strategy was successful at lowering ($P < 0.003$) IV when compared to feeding DDGS throughout; however, it was not successful ($P < 0.001$) at fully lowering IV to values similar to pigs fed the control diet throughout. Iodine value of the jowl ($P < 0.07$), loin ($P < 0.02$), and clear plate ($P < 0.003$) tended to be or were greater for IC pigs than barrows on d 107, but differences in IV between IC and barrows disappeared by d 125. Similar to previous studies, withdrawing DDGS from the diet before harvest can improve carcass fat quality (IV) and recover yield loss, but F/G was still poorer regardless of withdrawal strategy.

Overall, immunocastrates had reduced carcass yields, but they also had reduced ADFI and improved ADG, which led to improved feed efficiency. Although the use of Improvest can increase IV of fat depots when pigs are harvested at a shorter interval after the second injection, extending the feeding duration after the second injection returns IV to values similar to barrows. Another interesting observation is the magnitude of changes in fatty acid profile or IV between the different fat depots in relationship to rations, genders, and days after second injection with the immunocastrated barrows exhibiting larger changes than the contemporary physically castrated barrows.

Key words: DDGS, Improvest, finishing pig, withdrawal

Introduction

By-products such as dried distillers grains with solubles (DDGS) are often used as alternatives to corn and soybean meal in swine diets. Although these ingredients are used with the intent of lowering feed costs, they have been shown to negatively affect performance and carcass characteristics. One main area of concern is the reduction in carcass yield with pigs fed high-fiber diets as well as the negative effect of DDGS on fat quality. Soft carcass fat with a high iodine value (more unsaturated fat) has consistently been observed in pigs fed high levels of DDGS; however, removing DDGS as the source of unsaturated fat from the diet prior to harvest lowers carcass fat IV.

Improvest (Pfizer Animal Health, Kalamazoo, MI), an immunocastration technology, allows pigs to perform as boars until the second immunization injection. After the second immunization, IC pigs rapidly increase feed intake and growth rate. Our hypothesis was that pigs administered Improvest would deposit less fat prior to the second dose with a greater portion of their total fat deposition occurring late in the finishing stage; thus, we speculated that feeding high levels of unsaturated fat prior to the second dose would have less overall impact on IV with these pigs when less unsaturated fat is fed during the phase after the second dose.

Previous research has shown that reducing the level of DDGS in the diet before harvest has been successful in improving carcass yield and improving fat quality; however, no studies are available to determine the impact of the DDGS withdrawal strategy in combination with immunocastration. The objective of this trial was to determine the effects of withdrawing DDGS from the diets of barrows and immunocastrates prior to market on growth performance and carcass fat quality of growing-finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to feed and water.

A total of 1,360 pigs (PIC 1050 × 337, initially 53.0 lb) were used in a 125-d study. All pigs used in the study were individually tagged and tattooed at birth in sequential order; to minimize maternal effects, even numbers of pigs were used from each sow. To create gender differences, all odd-numbered pigs were left intact and even-numbered pigs were surgically castrated at 2 d of age per standard farm procedures. At weaning (~19 d of age), all pigs were transported to the commercial wean-to-finish barn and double-stocked in pens by gender (the other half of the barn was stocked with gilts). When pigs reached ~50 lb, all gilts were removed and pens were split by gender (barrow and boar) to single-stocking density. Pens of pigs (~28 barrows per pen or ~28 boars per pen) were randomly allotted by initial weight to 1 of 6 dietary treatments with 8 replications per treatment. Treatments were arranged in a 2 × 3 factorial with the main effects of gender (barrow vs. immunocastrate) and dietary DDGS duration (0% throughout, 30% throughout, or 30% from d 0 to 74 and no DDGS from d 74 to market). Dietary treatments were corn-soybean meal–based and fed in 5 phases (Tables 1 and 2). All diets were fed in meal form. On d 39 (~110 d of age), all boar pigs were administered a 2-ml primer dose of Improvest (Pfizer Animal Health, Kalamazoo, MI) in the high lateral aspect of the neck by a Pfizer Animal Health certified injection team (PAH), who also administered the second 2-ml dose on d 74 (~145 d of age). A PAH quality assurance check was performed on d 88 to ensure all pigs received both doses and did not exhibit any signs of typical boar behavior. Any pig thought to be a "suspect pig" (21 total) was re-dosed with an additional 2 ml of Improvest in the high lateral aspect of the neck, and the individual pig ID was recorded.

Pens of pigs were weighed and feed disappearance was recorded at d 0, 25, 53, 74, 87, 107, and 125 to determine ADG, ADFI, and F/G. On d 107 (180 d of age), all pigs were weighed individually and the 9 heaviest pigs per pen were selected (topped) and tattooed by pen to be transported to Natural Food Holdings (Sioux Center, IA). At that time, an additional 4 median weight pigs in each pen (4 pigs per pen, 32 pigs per treatment) were also identified to gain representative fat samples over time. These pigs were individually tattooed with a unique number (1 through 192), and 2 pigs per pen (16 per treatment) were transported with the 9 topped pigs to Natural Food Holdings for harvest. During harvest, the 2 selected median weight pigs were sequenced with a unique number corresponding to the tattoo given at the farm to allow for further tracking. The day after harvest, the left side of each carcass was transported by refrigerated truck to the University of Illinois Meat Sciences Laboratory (Urbana, IL) for full carcass breakdown. Standard carcass criteria of HCW and percentage carcass yield were collected on all pigs harvested. The other 2 median-weight pigs remained in their respective pens and were harvested on d 125, then transported to the University of Illinois Meat Sciences Laboratory for carcass processing. Fat samples were collected for both harvest dates from 4 fat depots (jowl, 10^{th} rib, clear plate, and belly) at the University of Illinois Meat Sciences Laboratory. These fat samples were then transported frozen to the K-State Analytical Lab (Manhattan, KS) for full fatty acid analyses. Percentage yield was calculated by dividing HCW at the plant by live weight at the plant.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of gender and DDGS during withdrawal, as well as interactive effects, were tested. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

No gender × diet interactions ($P > 0.18$) occurred with the exception of a tendency in F/G ($P < 0.07$) during the second phase (d 25 to 53), in which 1 of the 2 barrow groups fed 30% DDGS had an increase in ADFI resulting in poorer F/G. The other interaction tendency ($P < 0.07$) was for carcass yield on d 107, where there was a greater reduction in carcass yield for IC pigs compared with barrows when fed DDGS throughout than when fed the control diet throughout or when DDGS was withdrawn from the diet on d 74. Barrows had greater ($P < 0.01$) ADG (1.92 vs. 1.85) than boars from d 0 to 25 (Tables 3 and 4), which resulted in a tendency for barrows to have greater ($P < 0.08$) ADG than boars prior to the second Improvest immunization (d 74; Tables 5 and 6). Boars had decreased ($P < 0.001$) ADFI and improved ($P < 0.001$) F/G for all periods prior to the second immunization. Immediately after the second immunization (d 74 to 87), IC pigs continued to have lower ($P < 0.001$) ADFI, but grew faster ($P < 0.03$) than barrows, resulting in improved ($P < 0.001$) F/G. After this 2-wk period, feed intake increased rapidly in IC pigs such that they had greater ($P < 0.001$) ADFI for the last two phases of the trial (d 87 to 107 and d 107 to 125) than barrows. The higher feed intake allowed IC pigs to have much greater ($P < 0.001$) ADG during the last two phases than barrows. Feed efficiency also improved ($P < 0.01$) from d 87 to 107 for IC pigs but was similar to barrows from d 107 to 125.

For the period after the second Improvest injection until the first marketing event (d 74 to 107; 33 d after the second dose), IC pigs had increased ($P < 0.01$) ADG and were more efficient ($P < 0.01$; 3.02 vs. 3.25) than barrows. From d 0 to 107, IC pigs had improved ($P < 0.03$) ADG (2.05 vs. 2.01 lb), F/G (2.34 vs. 2.52), and lower ($P < 0.001$) ADFI (4.80 vs. 5.06 lb) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender did not influence ADG or ADFI but did worsen ($P < 0.001$) feed efficiency.

For the period after the second Improvest injection to the end of the trial (d 74 to 125; 51 d after the second dose), IC pigs had increased ($P < 0.01$) ADG (2.29 vs. 2.10) and ADFI (7.09 vs. 6.82) and were more efficient ($P < 0.01$; 3.09 vs. 3.25) than barrows. Overall (d 0 to 125), IC pigs had improved ($P < 0.003$) ADG (2.07 vs. 2.02) and F/G (2.44 vs. 2.58) and lower ADFI (5.05 vs. 5.22) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender again did not influence ADG or ADFI but worsened ($P < 0.001$) feed efficiency.

Regardless of gender, pigs fed 30% DDGS had decreased ($P < 0.02$) ADG compared with pigs fed the control diet without DDGS from d 0 to 25, d 25 to 53, and for the entire period prior to the second Improvest immunization (d 74). Withdrawing DDGS from the diet on d 74 did not influence pig performance from d 74 to 107 but resulted in lower ($P < 0.001$) ADFI and improved ($P < 0.001$) F/G from d 107 to 125. The inclusion of 30% DDGS did not influence ($P > 0.12$) overall ADG or ADFI but worsened ($P = 0.001$) F/G regardless of withdrawal strategy.

Carcass yield was lower ($P < 0.001$) for IC pigs than barrows regardless of diet type or withdrawal strategy. Pigs fed the 30% DDGS diet throughout had decreased ($P < 0.001$) carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss, returning yield to levels similar to that of the pigs fed the corn-soybean meal diet throughout. Final HCW were not influenced ($P > 0.11$) by treatment. Carcass fat IV were greater when 30% DDGS were included in the diet. The withdrawal strategy was successful at lowering the IV compared with pigs fed DDGS throughout; however, as observed in previous studies, it was not successful at fully lowering IV to values similar to pigs fed the control diet throughout.

Fatty Acid Analysis on d 107

All fat depots responded similarly to treatment, so results will be discussed together (Tables 7, 8, 11, 12, 15, 16, 19, and 20). Including 30% DDGS reduced ($P < 0.001$) SFA and MUFA proportions regardless of fat depot. Of the predominant SFA ($P < 0.02$), myristic (14:0), palmitic (16:0), and stearic (18:0) acid concentrations were reduced ($P < 0.01$) as well as MUFA concentrations of palmitoleic (16:1), oleic (18:1c9), and vaccenic (18:1n7) acids. Total *trans* and PUFA, however, were increased ($P < 0.04$) due to increases in linoleic (18:2n6), α-linoleic (18:3n3), eicosadienoic (20:2), and arachidonic (20:4n-6) acid concentrations, resulting in overall increases ($P < 0.001$) in UFA:SFA and PUFA:SFA ratios as well as IV. Withdrawing DDGS from the diet on d 74 reduced ($P < 0.03$) SFA concentrations through reductions in 16:0 and 18:0 and tended to reduce MUFA by reducing 18:1c9. Total *trans* and PUFA concentration increased ($P < 0.05$) by 18:2n6, 18:3n3, and 20:2 concentration, which resulted in overall increases ($P < 0.02$) in UFA:SFA, PUFA:SFA, and IV. The IC pigs had reduced ($P < 0.04$) MUFA proportions as a result of reductions in 18:1c9 and 20:1 concentrations. The IC pigs also had lower ($P < 0.02$) 14:0 concentrations but no difference in overall SFA; however, total PUFA was increased ($P < 0.01$) through increases ($P < 0.04$) in 18:2n6, 18:3n3, 20:2, and 20:4n6, causing an overall increase ($P < 0.02$) in PUFA:SFA ratio. Iodine values were increased ($P < 0.02$) in loin and clear plate samples and tended to increase ($P < 0.07$) in jowl samples for IC pigs compared with barrows, but no difference was detected in IV for belly fat samples.

Fatty Acid Analyses on d 125

From d 107 to d 125 fatty acid profiles of immunocastrates changed dramatically through reductions in PUFA, mainly 18:2n6, 18:3n3, 20:2, and 20:4n6 (Tables 9, 10, 13, 14, 17, 18, 21, and 22). These reductions in unsaturated fatty acid concentration resulted in improved IV, resulting in values that were not statistically different, and in some cases numerically better than that of barrows. Despite increases ($P < 0.05$) in 17:0, including 30% DDGS in the diet reduced ($P < 0.001$) SFA and MUFA proportions through reductions ($P < 0.01$) in SFA concentrations of 14:0 and 16:0 and MUFA concentrations ($P < 0.01$) of 16:1, 18:1c9, and 18:1n7. Total *trans* and PUFA were increased ($P < 0.003$) by increases ($P < 0.004$) in 18:2n6, 18:3n3, 20:2, and 20:4n6, which resulted in overall increases ($P < 0.001$) in UFA:SFA, PUFA:SFA, and IV when 30% DDGS were included in the diet. Withdrawing DDGS from the diet on d 74 reduced ($P < 0.002$) SFA and MUFA proportions through reductions ($P < 0.001$) in SFA concentrations of 16:0 and 18:0 (except in jowl fat samples) and MUFA concentrations ($P < 0.05$) of 16:1, 18:1c9, and 18:n7; however, PUFA was increased ($P < 0.001$) through increases ($P < 0.04$) in 18:2n6, 18:3n3, and 20:2, which resulted in overall increases ($P < 0.04$) in UFA:SFA, PUFA:SFA, and IV. The IC pigs tended ($P < 0.10$) to have reduced MUFA proportions as a result of reductions ($P < 0.09$) in 18:1c9 and 18:1n7 concentrations, but no differences were detected in UFA:SFA, PUFA:SFA, or IV between IC pigs and barrows.

The change in fatty acid profile and IV between fat stores and by days post–second injection of Improvest are shown in Tables 23 and 24 and Figure 1. The IV of jowl fat is considerably greater than the IV of backfat, belly fat, or clear plate regardless of gender or dietary regimen. Increasing feeding duration from 33 to 51 d post–second injection reduced IV for backfat and belly fat for IC pigs but did not influence IV of jowl or clear plate fat. These results would be expected, because more of the fat in the late finishing period is being deposited in the belly and backfat. The data also demonstrate the difference in conclusion depending on which fat source is being measured. For jowl fat, IV was greater for IC pigs than barrows regardless of diet and did not decrease with days on feed. For backfat and belly fat, increasing days on feed from d 107 to d 125 reduced IV, with IC pigs having a much greater reduction in IV than barrows.

Withdrawing DDGS from the diet prior to harvest, regardless of gender, can regain yield loss and improve IV; however, regardless of withdrawal strategy, feed efficiency was poorer when feeding DDGS. Immunocastrates had reduced carcass yields regardless of diet type compared with barrows, but they also had reduced ADFI and improved ADG, which resulted in improved F/G. Although Improvest can increase IV of fat depots when pigs are harvested at 5 wk post–second injection, extending the length of feeding duration prior to harvest after the second injection returns IV values to levels similar to those of barrows.

Table 1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1		Phase 2	
Item DDGS, %:[2]	0	30	0	30
Ingredient, %				
Corn	67.85	45.25	72.90	50.20
Soybean meal (46.5% CP)	29.45	22.40	24.70	17.55
DDGS	---	30.00	---	30.00
Monocalcium P (21% P)	0.60	---	0.45	---
Limestone	0.90	1.20	0.90	1.20
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09	0.09
L-threonine	0.09	0.04	0.08	0.03
DL-methionine	0.12	0.01	0.07	---
L-lysine sulfate	0.51	0.64	0.45	0.58
Phytase[3]	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	1.14	1.14	1.00	1.00
Isoleucine:lysine	61	63	62	64
Leucine:lysine	130	157	139	169
Methionine:lysine	32	29	30	30
Met & Cys:lysine	56	56	56	60
Threonine:lysine	62	62	63	63
Tryptophan:lysine	18	18	18	18
Valine:lysine	66	72	68	76
SID lysine:ME, g/Mcal	3.41	3.39	2.98	2.98
ME, kcal/lb	1,518	1,524	1,521	1,525
Total lysine, %	1.26	1.33	1.11	1.18
CP, %	19.9	22.9	18.1	21.0
Ca, %	0.57	0.55	0.53	0.54
Crude fiber, %	2.6	4.1	2.6	4.0
P, %	0.52	0.50	0.47	0.48
Available P, %	0.30	0.32	0.27	0.32

[1] Phase 1 diets were fed from approximately 50 to 100 lb; Phase 2 diets were fed from 100 to 150 lb.
[2] DDGS: dried distillers grains with solubles.
[3] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per pound of diet: 454.0 phytase units (FTU)/lb and 0.11% available P released.

Table 2. Phase 3, 4, and 5 diet composition (as-fed basis)[1]

	Phase 3		Phase 4		Phase 5	
Item DDGS, %:[2]	0	30	0	30	0	30
Ingredient, %						
Corn	75.75	53.00	80.10	57.15	85.30	62.25
Soybean meal (46.5% CP)	22.00	14.75	17.80	10.70	12.75	5.65
DDGS	---	30.00	---	30.00	---	30.00
Monocalcium P (21% P)	0.35	---	0.30	---	0.30	---
Limestone	0.90	1.20	0.85	1.20	0.85	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.09	0.09	0.09	0.09	0.09	0.09
L-threonine	0.07	0.02	0.06	0.02	0.03	---
DL-methionine	0.04	---	0.03	---	---	---
L-lysine sulfate	0.42	0.55	0.37	0.50	0.31	0.44
Phytase[3]	0.01	0.01	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.92	0.92	0.80	0.80	0.65	0.65
Isoleucine:lysine	63	65	64	67	67	71
Leucine:lysine	146	178	157	194	177	223
Methionine:lysine	29	31	30	34	31	39
Met & Cys:lysine	56	63	59	68	63	78
Threonine:lysine	64	64	66	66	66	69
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	70	78	73	82	79	90
SID lysine:ME, g/Mcal	2.74	2.74	2.38	2.38	1.93	1.93
ME, kcal/lb	1,523	1,525	1,525	1,526	1,525	1,526
Total lysine, %	1.03	1.09	0.90	0.96	0.73	0.80
CP, %	17.0	20.0	15.4	18.4	13.4	16.4
Ca, %	0.50	0.53	0.46	0.52	0.45	0.50
Crude fiber, %	2.5	3.9	2.5	3.9	2.4	3.8
P, %	0.44	0.46	0.41	0.45	0.39	0.43
Available P, %	0.24	0.31	0.23	0.31	0.22	0.30

[1] Phase 3 diets were fed from approximately 150 to 200 lb, Phase 4 diets were fed from 200 to 230 lb, and Phase 5 diets were fed from 230 to 280 lb.
[2] DDGS: dried distillers grains with solubles.
[3] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per pound of diet: 454.0 phytase units (FTU)/lb and 0.11% available P released.

Table 3. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on growth performance[1]

Gender:	Barrow			Improvest			
d 0 to 74:	Corn-soy	30% DDGS	30% DDGS	Corn-soy	30% DDGS	30% DDGS	
d 74 to 125:	Corn-soy	Corn-soy	30% DDGS	Corn-soy	Corn-soy	30% DDGS	SEM
d 0 to 25							
ADG, lb	1.99	1.89	1.88	1.92	1.80	1.84	0.03
ADFI, lb	3.47	3.38	3.33	3.23	3.14	3.19	0.07
F/G	1.75	1.79	1.77	1.68	1.75	1.74	0.03
d 25 to 53[2]							
ADG, lb	1.79	1.72	1.73	1.79	1.73	1.74	0.03
ADFI, lb	4.05	4.27	3.99	3.59	3.66	3.69	0.09
F/G	2.26	2.49	2.31	2.01	2.12	2.13	0.04
d 53 to 74[3]							
ADG, lb	2.36	2.37	2.38	2.37	2.34	2.31	0.04
ADFI, lb	5.80	5.73	5.83	5.23	5.16	5.11	0.09
F/G	2.46	2.42	2.45	2.21	2.21	2.22	0.03
d 74 to 87							
ADG, lb	2.15	2.14	2.20	2.26	2.26	2.19	0.04
ADFI, lb	6.59	6.63	6.65	5.87	6.09	5.91	0.11
F/G	3.07	3.10	3.03	2.60	2.70	2.70	0.04
d 87 to 107							
ADG, lb	2.00	2.03	2.12	2.25	2.34	2.41	0.07
ADFI, lb	6.66	7.05	7.10	7.34	7.57	7.81	0.17
F/G	3.36	3.49	3.35	3.27	3.24	3.25	0.07
d 107 to 125							
ADG, lb	2.06	2.14	2.11	2.28	2.33	2.28	0.07
ADFI, lb	6.70	6.68	7.15	7.29	7.53	8.08	0.13
F/G	3.28	3.12	3.39	3.20	3.25	3.55	0.07

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 53.0 lb) were used in a 125-d study.
[2] First Improvest injection was given on d 39.
[3] Second Improvest injection was given on d 74.

Table 4. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on growth performance[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS before[5]	DDGS withdrawal[6]
d 0 to 25					
ADG, lb	0.66	0.01	0.001	0.001	
ADFI, lb	0.71	0.001	0.35	0.15	
F/G	0.85	0.04	0.14	0.05	
d 25 to 53					
ADG, lb	0.95	0.78	0.08	0.03	
ADFI, lb	0.22	0.001	0.20	0.27	
F/G	0.07	0.001	0.001	0.001	
d 53 to 74					
ADG, lb	0.61	0.42	0.86	0.64	
ADFI, lb	0.63	0.001	0.73	0.46	
F/G	0.73	0.001	0.65	0.75	
d 74 to 87					
ADG, lb	0.22	0.03	0.98		0.93
ADFI, lb	0.64	0.001	0.51		0.49
F/G	0.24	0.001	0.26		0.35
d 87 to 107					
ADG, lb	0.88	0.001	0.13		0.26
ADFI, lb	0.84	0.001	0.04		0.41
F/G	0.44	0.01	0.64		0.38
d 107 to 125					
ADG, lb	0.93	0.001	0.62		0.54
ADFI, lb	0.39	0.001	0.001		0.001
F/G	0.18	0.20	0.001		0.001

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 53.0 lb.) were used in a 125-d study.
[2] Interaction gender × diet.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before 2nd injection (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of withdrawing DDGS after 2nd injection (Treatments 2 and 5 vs. 3 and 6).

Table 5. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on overall growth performance and weights[1]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	30% DDGS	30% DDGS	Corn-soy	30% DDGS	30% DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	30% DDGS	Corn-soy	Corn-soy	30% DDGS	SEM
Weight, lb							
d 0	53.3	53.4	53.4	52.9	53.0	52.8	1.16
d 25[2]	103.0	100.7	100.4	101.0	98.1	98.9	1.75
d 53	153.3	149.0	148.9	151.3	147.4	147.8	2.04
d 74[3]	203.1	198.8	198.8	201.3	196.7	197.0	2.13
d 87	231.0	226.6	227.5	230.9	226.1	225.8	2.21
d 107	257.5	254.4	254.9	263.8	259.1	259.8	2.99
d 125	294.7	294.1	293.1	305.0	301.4	301.3	3.21
d 0 to 74							
ADG, lb	2.02	1.96	1.96	2.00	1.92	1.93	0.02
ADFI, lb	4.33	4.37	4.27	3.92	3.89	3.92	0.06
F/G	2.15	2.23	2.18	1.96	2.03	2.03	0.02
d 74 to 107							
ADG, lb	2.06	2.08	2.15	2.25	2.31	2.32	0.05
ADFI, lb	6.63	6.88	6.92	6.74	6.97	7.04	0.14
F/G	3.23	3.32	3.22	3.00	3.02	3.04	0.05
d 74 to 125							
ADG, lb	2.06	2.09	2.14	2.26	2.31	2.31	0.04
ADFI, lb	6.65	6.83	6.97	6.88	7.10	7.29	0.11
F/G	3.23	3.27	3.26	3.04	3.08	3.16	0.04
d 0 to 107							
ADG, lb	2.03	1.99	2.02	2.07	2.04	2.04	0.02
ADFI, lb	5.02	5.12	5.06	4.76	4.80	4.84	0.07
F/G	2.47	2.57	2.51	2.30	2.36	2.37	0.02
d 0 to 125							
ADG, lb	2.03	2.01	2.03	2.09	2.06	2.07	0.02
ADFI, lb	5.16	5.26	5.24	4.98	5.04	5.12	0.07
F/G	2.54	2.62	2.59	2.38	2.45	2.48	0.02
HCW, lb							
d 107	208.4	205.9	204.9	209.1	208.0	204.4	2.08
d 125	213.5	212.6	210.1	216.4	213.9	211.8	2.28
Yield, %							
d 107	76.6	76.4	75.9	74.8	74.8	73.6	0.13
d 125	76.3	76.2	75.8	74.9	74.8	74.0	0.16

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 53.0 lb.) were used in a 125-d study.
[2] First Improvest injection was given on d 39.
[3] Second Improvest injection was given on d 74.

Table 6. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on overall growth performance and weights[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS before[5]	DDGS withdrawal[6]
Weight, lb					
d 0	1.00	0.64	1.00	0.96	
d 25[2]	0.95	0.17	0.26	0.10	
d 53	0.98	0.36	0.08	0.03	
d 74[3]	1.00	0.29	0.07	0.02	
d 87	0.93	0.67	0.08		0.90
d 107	0.96	0.04	0.37		0.85
d 125	0.89	0.002	0.70		0.87
d 0 to 74					
ADG, lb	0.92	0.08	0.002	0.001	
ADFI, lb	0.60	0.001	0.77	0.74	
F/G	0.39	0.001	0.005	0.002	
d 74 to 107					
ADG, lb	0.78	<0.001	0.24		0.35
ADFI, lb	0.99	0.35	0.10		0.72
F/G	0.44	<0.001	0.41		0.34
d 74 to 125					
ADG, lb	0.81	0.001	0.24		0.55
ADFI, lb	0.93	0.01	0.01		0.15
F/G	0.43	0.001	0.21		0.34
d 0 to 107					
ADG, lb	0.91	0.03	0.22	0.13	0.41
ADFI, lb	0.80	<0.001	0.58	0.30	0.88
F/G	0.37	<0.001	0.01	0.001	0.26
d 0 to 125					
ADG, lb	0.89	0.003	0.37	0.21	0.53
ADFI, lb	0.76	0.003	0.26	0.12	0.59
F/G	0.33	0.001	0.01	0.001	0.97
HCW, lb					
d 107	0.83	0.66	0.15	0.11	0.28
d 125	0.94	0.30	0.23	0.16	0.32
Yield, %					
d 107	0.07	0.001	0.001		0.001
d 125	0.41	0.001	0.001		0.001

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 53.0 lb.) were used in a 125-d study.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before 2nd injection (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of withdrawing DDGS after 2nd injection (Treatments 2 and 5 vs. 3 and 6).

Table 7. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.34	1.30	1.25	1.28	1.22	1.20	0.03
Palmitic acid (C16:0), %	23.16	21.74	21.17	22.02	21.64	21.05	0.30
Palmitoleic acid (C16:1), %	2.47	2.36	2.15	2.40	2.12	2.12	0.11
Margaric acid (C17:0), %	0.59	0.66	0.72	0.62	0.62	0.67	0.04
Stearic acid (C18:0), %	11.72	10.21	9.95	11.53	11.52	10.23	0.36
Oleic acid (C18:1 *cis*-9), %	39.59	37.36	36.20	38.05	35.76	35.31	0.47
Vaccenic acid (C18:1n-7), %	3.82	3.62	3.35	3.77	3.36	3.32	0.10
Linoleic acid (C18:2n-6), %	12.80	17.73	19.99	15.53	18.85	20.77	0.63
α-Linoleic acid (C18:3n-3), %	0.58	0.69	0.73	0.71	0.72	0.74	0.03
Arachidic acid (C20:0), %	0.24	0.22	0.24	0.21	0.23	0.21	0.01
Gadoleic acid (C20:1), %	0.88	0.85	0.83	0.80	0.80	0.84	0.02
Eicosadienoic acid (C20:2), %	0.75	0.97	1.07	0.84	1.00	1.13	0.04
Arachidonic acid (C20:4n-6), %	0.27	0.31	0.31	0.34	0.36	0.36	0.01
Other fatty acids, %	1.79	1.98	2.04	1.90	1.81	2.06	0.06
Total SFA, %	37.31	34.39	33.59	35.93	35.49	33.64	0.58
Total MUFA, %	46.88	44.31	42.64	45.12	42.14	41.72	0.62
Total PUFA, %	14.68	20.01	22.44	17.73	21.20	23.38	0.70
Total *trans* fatty acids, %	0.90	1.07	1.13	1.03	1.00	1.12	0.03
UFA:SFA ratio	1.66	1.88	1.95	1.76	1.80	1.96	0.05
PUFA:SFA ratio	0.40	0.58	0.67	0.50	0.61	0.71	0.03
Iodine value, g/100g	64.8	71.5	74.1	68.4	71.5	74.8	0.92

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 8. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 107[1]

	Probability, $P<$				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.89	0.01	0.01	0.005	0.17
Palmitic acid (C16:0), %	0.15	0.07	<0.001	<0.001	0.06
Palmitoleic acid (C16:1), %	0.62	0.21	0.03	0.01	0.32
Margaric acid (C17:0), %	0.49	0.47	0.05	0.05	0.13
Stearic acid (C18:0), %	0.11	0.12	<0.001	<0.001	0.03
Oleic acid (C18:1 *cis*-9), %	0.70	0.001	<0.001	<0.001	0.09
Vaccenic acid (C18:1n-7), %	0.47	0.17	<0.001	<0.001	0.14
Linoleic acid (C18:2n-6), %	0.26	0.004	<0.001	<0.001	0.002
α-Linoleic acid (C18:3n-3), %	0.08	0.01	0.005	0.002	0.24
Arachidic acid (C20:0), %	0.09	0.10	0.99	0.99	0.91
Gadoleic acid (C20:1), %	0.09	0.02	0.76	0.60	0.60
Eicosadienoic acid (C20:2), %	0.75	0.04	<0.001	<0.001	0.002
Arachidonic acid (C20:4n-6), %	0.67	<0.001	0.01	0.002	0.71
Other fatty acids, %	0.06	0.76	0.003	0.02	0.01
Total SFA, %[7]	0.11	0.87	<0.001	<0.001	0.03
Total MUFA, %[8]	0.59	0.003	<0.001	<0.001	0.10
Total PUFA, %[9]	0.27	0.004	<0.001	<0.001	0.002
Total *trans* fatty acids, %[10]	0.02	0.49	<0.001	<0.001	0.02
UFA:SFA ratio[11]	0.21	0.78	<0.001	<0.001	0.02
PUFA:SFA ratio[12]	0.32	0.02	<0.001	<0.001	0.001
Iodine value, g/100g[13]	0.12	0.07	<0.001	<0.001	0.003

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 9. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.33	1.25	1.22	1.35	1.20	1.22	0.03
Palmitic acid (C16:0), %	22.60	20.95	20.50	22.44	20.99	20.71	0.26
Palmitoleic acid (C16:1), %	2.53	2.46	2.17	2.56	2.31	2.03	0.10
Margaric acid (C17:0), %	0.60	0.63	0.66	0.59	0.65	0.60	0.03
Stearic acid (C18:0), %	10.82	9.64	9.01	10.83	10.04	9.84	0.25
Oleic acid (C18:1 *cis*-9), %	40.44	38.36	37.26	38.94	37.94	35.78	0.37
Vaccenic acid (C18:1n-7), %	3.84	3.66	3.34	3.78	3.52	3.13	0.08
Linoleic acid (C18:2n-6), %	13.43	18.24	20.84	15.02	18.51	21.85	0.41
α-Linoleic acid (C18:3n-3), %	0.61	0.70	0.73	0.67	0.71	0.75	0.02
Arachidic acid (C20:0), %	0.21	0.22	0.21	0.21	0.21	0.21	0.01
Gadoleic acid (C20:1), %	0.90	0.82	0.84	0.85	0.84	0.80	0.02
Eicosadienoic acid (C20:2), %	0.79	0.98	1.13	0.83	1.03	1.15	0.03
Arachidonic acid (C20:4n-6), %	0.26	0.30	0.30	0.27	0.31	0.31	0.01
Other fatty acids, %	1.64	1.79	1.79	1.67	1.74	1.62	0.04
Total SFA, %	35.81	32.91	31.81	35.66	33.33	32.81	0.43
Total MUFA, %	47.76	45.37	43.67	46.20	44.68	41.81	0.45
Total PUFA, %	15.31	20.50	23.26	17.00	20.80	24.31	0.46
Total *trans* fatty acids, %	0.90	1.06	1.06	0.98	1.03	1.02	0.03
UFA:SFA ratio	1.77	2.01	2.11	1.78	1.97	2.03	0.04
PUFA:SFA ratio	0.43	0.63	0.73	0.48	0.63	0.74	0.02
Iodine value, g/100g	66.6	73.3	76.4	68.2	73.1	76.4	0.65

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 10. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 125[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.54	0.75	0.001	0.001	0.78
Palmitic acid (C16:0), %	0.77	0.88	0.001	0.001	0.17
Palmitoleic acid (C16:1), %	0.60	0.30	0.001	0.001	0.01
Margaric acid (C17:0), %	0.45	0.54	0.36	0.16	0.80
Stearic acid (C18:0), %	0.27	0.05	0.001	0.001	0.11
Oleic acid (C18:1 *cis*-9), %	0.26	0.001	0.001	0.001	0.001
Vaccenic acid (C18:1n-7), %	0.62	0.04	0.001	0.001	0.001
Linoleic acid (C18:2n-6), %	0.28	0.01	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.25	0.07	0.001	0.001	0.04
Arachidic acid (C20:0), %	0.88	0.91	0.74	0.50	0.70
Gadoleic acid (C20:1), %	0.21	0.23	0.04	0.01	0.68
Eicosadienoic acid (C20:2), %	0.80	0.13	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.87	0.54	0.002	0.001	0.84
Other fatty acids, %	0.12	0.09	0.06	0.05	0.16
Total SFA, %[7]	0.43	0.24	0.001	0.001	0.07
Total MUFA, %[8]	0.41	0.001	0.001	0.001	0.001
Total PUFA, %[9]	0.31	0.01	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.03	0.95	0.001	0.001	0.94
UFA:SFA ratio[11]	0.42	0.25	0.001	0.001	0.04
PUFA:SFA ratio[12]	0.39	0.21	0.001	0.001	0.001
Iodine value, g/100g[13]	0.35	0.37	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 11. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.36	1.34	1.29	1.34	1.25	1.22	0.03
Palmitic acid (C16:0), %	25.41	24.30	23.22	24.53	23.80	22.95	0.34
Palmitoleic acid (C16:1), %	2.09	1.95	1.79	2.07	1.82	1.76	0.09
Margaric acid (C17:0), %	0.65	0.66	0.75	0.65	0.64	0.67	0.04
Stearic acid (C18:0), %	14.80	13.57	12.32	14.48	14.03	12.33	0.34
Oleic acid (C18:1 *cis*-9), %	35.83	34.43	32.84	34.66	33.35	32.52	0.42
Vaccenic acid (C18:1n-7), %	3.11	2.93	2.71	3.07	2.82	2.69	0.06
Linoleic acid (C18:2n-6), %	12.77	16.45	20.46	15.01	17.93	21.27	0.62
α-Linoleic acid (C18:3n-3), %	0.54	0.61	0.68	0.64	0.66	0.69	0.02
Arachidic acid (C20:0), %	0.30	0.28	0.29	0.27	0.29	0.28	0.01
Gadoleic acid (C20:1), %	0.80	0.78	0.72	0.72	0.72	0.73	0.02
Eicosadienoic acid (C20:2), %	0.66	0.82	0.95	0.71	0.85	0.99	0.03
Arachidonic acid (C20:4n-6), %	0.23	0.25	0.27	0.28	0.29	0.28	0.01
Other fatty acids, %	1.50	1.63	1.70	1.58	1.55	1.62	0.04
Total SFA, %	42.77	40.38	38.12	41.54	40.26	37.70	0.59
Total MUFA, %	41.92	40.18	38.14	40.58	38.79	37.77	0.52
Total PUFA, %	14.38	18.35	22.60	16.85	19.95	23.48	0.68
Total *trans* fatty acids, %	0.80	0.93	1.01	0.92	0.92	0.97	0.03
UFA:SFA ratio	1.32	1.45	1.60	1.39	1.47	1.64	0.04
PUFA:SFA ratio	0.34	0.46	0.60	0.41	0.50	0.63	0.02
Iodine value, g/100g	60.1	65.3	70.8	63.2	66.8	71.8	0.96

[1] All values are on a DM basis.
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 12. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 107[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.50	0.02	0.01	0.01	0.25
Palmitic acid (C16:0), %	0.67	0.05	0.001	0.001	0.01
Palmitoleic acid (C16:1), %	0.80	0.42	0.01	0.003	0.24
Margaric acid (C17:0), %	0.52	0.33	0.19	0.38	0.11
Stearic acid (C18:0), %	0.53	0.86	0.001	0.001	0.001
Oleic acid (C18:1 *cis*-9), %	0.57	0.02	0.001	0.001	0.01
Vaccenic acid (C18:1n-7), %	0.75	0.28	0.001	0.001	0.01
Linoleic acid (C18:2n-6), %	0.53	0.005	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.24	0.01	0.002	0.002	0.05
Arachidic acid (C20:0), %	0.24	0.14	0.99	0.97	0.92
Gadoleic acid (C20:1), %	0.17	0.01	0.28	0.30	0.23
Eicosadienoic acid (C20:2), %	0.97	0.16	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.41	0.001	0.20	0.07	0.82
Other fatty acids, %	0.11	0.41	0.03	0.04	0.10
Total SFA, %[7]	0.64	0.23	0.001	0.001	0.001
Total MUFA, %[8]	0.56	0.02	0.001	0.001	0.01
Total PUFA, %[9]	0.52	0.01	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.02	0.30	0.001	0.001	0.03
UFA:SFA ratio[11]	0.79	0.21	0.001	0.001	0.001
PUFA:SFA ratio[12]	0.73	0.02	0.001	0.001	0.001
Iodine value, g/100g[13]	0.54	0.02	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS)..
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 13. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.35	1.33	1.27	1.38	1.29	1.28	0.03
Palmitic acid (C16:0), %	25.60	24.51	23.19	25.86	24.80	23.52	0.26
Palmitoleic acid (C16:1), %	2.10	2.05	1.73	2.03	1.95	1.68	0.09
Margaric acid (C17:0), %	0.53	0.57	0.65	0.52	0.58	0.60	0.03
Stearic acid (C18:0), %	14.97	13.99	12.48	15.52	14.49	13.27	0.30
Oleic acid (C18:1 *cis*-9), %	37.29	35.48	33.54	35.92	36.31	32.60	0.40
Vaccenic acid (C18:1n-7), %	3.08	2.94	2.64	2.94	2.91	2.53	0.06
Linoleic acid (C18:2n-6), %	11.27	14.97	20.15	12.08	13.73	20.28	0.49
α-Linoleic acid (C18:3n-3), %	0.48	0.53	0.64	0.49	0.49	0.63	0.02
Arachidic acid (C20:0), %	0.30	0.31	0.28	0.30	0.30	0.27	0.01
Gadoleic acid (C20:1), %	0.83	0.79	0.76	0.82	0.82	0.72	0.03
Eicosadienoic acid (C20:2), %	0.62	0.77	0.96	0.62	0.72	0.94	0.02
Arachidonic acid (C20:4n-6), %	0.20	0.23	0.24	0.20	0.22	0.25	0.01
Other fatty acids, %	1.37	1.51	1.48	1.31	1.39	1.45	0.04
Total SFA, %	43.01	40.96	38.11	43.82	41.69	39.19	0.46
Total MUFA, %	43.38	41.34	38.73	41.77	42.06	37.59	0.47
Total PUFA, %	12.75	16.72	22.18	13.56	15.33	22.28	0.53
Total *trans* fatty acids, %	0.71	0.84	0.89	0.74	0.74	0.89	0.03
UFA:SFA ratio	1.31	1.42	1.61	1.27	1.38	1.54	0.03
PUFA:SFA ratio	0.30	0.41	0.59	0.31	0.37	0.57	0.02
Iodine value, g/100g	58.6	63.6	70.4	58.7	61.8	69.7	0.73

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 14. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 125[1]

	Probability, $P<$				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.50	0.93	0.02	0.01	0.26
Palmitic acid (C16:0), %	0.99	0.18	0.001	0.001	0.001
Palmitoleic acid (C16:1), %	0.95	0.30	0.001	0.01	0.001
Margaric acid (C17:0), %	0.62	0.51	0.02	0.01	0.16
Stearic acid (C18:0), %	0.87	0.02	0.001	0.001	0.001
Oleic acid (C18:1 *cis*-9), %	0.02	0.13	0.001	0.001	0.001
Vaccenic acid (C18:1n-7), %	0.67	0.06	0.001	0.001	0.001
Linoleic acid (C18:2n-6), %	0.11	0.81	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.27	0.41	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.68	0.50	0.01	0.30	0.01
Gadoleic acid (C20:1), %	0.43	0.66	0.004	0.02	0.02
Eicosadienoic acid (C20:2), %	0.58	0.20	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.80	0.73	0.001	0.001	0.10
Other fatty acids, %	0.58	0.05	0.01	0.002	0.73
Total SFA, %[7]	0.92	0.02	0.001	0.001	0.001
Total MUFA, %[8]	0.04	0.08	0.001	0.001	0.001
Total PUFA, %[9]	0.11	0.71	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.07	0.27	0.001	0.001	0.001
UFA:SFA ratio[11]	0.85	0.03	0.001	0.001	0.001
PUFA:SFA ratio[12]	0.30	0.35	0.001	0.001	0.001
Iodine value, g/100g[13]	0.46	0.17	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 15. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.39	1.36	1.31	1.36	1.28	1.22	0.03
Palmitic acid (C16:0), %	24.44	23.28	22.54	23.74	23.29	22.27	0.33
Palmitoleic acid (C16:1), %	2.59	2.38	2.26	2.54	2.15	2.11	0.12
Margaric acid (C17:0), %	0.54	0.58	0.62	0.55	0.53	0.57	0.03
Stearic acid (C18:0), %	12.35	11.40	10.84	12.64	12.76	11.11	0.46
Oleic acid (C18:1 *cis*-9), %	39.28	37.44	36.17	37.98	36.36	35.58	0.50
Vaccenic acid (C18:1n-7), %	3.78	3.50	3.35	3.73	3.35	3.22	0.11
Linoleic acid (C18:2n-6), %	11.64	15.64	18.35	13.25	15.97	19.32	0.43
α-Linoleic acid (C18:3n-3), %	0.52	0.59	0.65	0.59	0.60	0.65	0.02
Arachidic acid (C20:0), %	0.25	0.24	0.25	0.23	0.26	0.24	0.01
Gadoleic acid (C20:1), %	0.83	0.82	0.78	0.76	0.77	0.77	0.02
Eicosadienoic acid (C20:2), %	0.66	0.85	0.93	0.73	0.83	1.00	0.03
Arachidonic acid (C20:4n-6), %	0.23	0.26	0.27	0.29	0.30	0.30	0.01
Other fatty acids, %	1.54	1.65	1.66	1.62	1.53	1.62	0.05
Total SFA, %	39.19	37.12	35.82	38.78	38.38	35.67	0.70
Total MUFA, %	46.56	44.22	42.63	45.11	42.71	41.76	0.66
Total PUFA, %	13.25	17.57	20.42	15.08	17.91	21.50	0.47
Total *trans* fatty acids, %	0.79	0.91	0.94	0.87	0.86	0.94	0.03
UFA:SFA ratio	1.54	1.67	1.77	1.57	1.60	1.79	0.05
PUFA:SFA ratio	0.34	0.48	0.57	0.39	0.47	0.61	0.02
Iodine value, g/100g	62.2	67.4	70.9	64.0	66.6	71.8	0.82

[1] All values are on a DM basis.
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 16. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 107[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.57	0.01	0.002	0.002	0.08
Palmitic acid (C16:0), %	0.55	0.23	0.001	0.001	0.01
Palmitoleic acid (C16:1), %	0.74	0.13	0.005	0.001	0.48
Margaric acid (C17:0), %	0.56	0.21	0.23	0.23	0.22
Stearic acid (C18:0), %	0.40	0.09	0.01	0.02	0.02
Oleic acid (C18:1 *cis*-9), %	0.77	0.02	0.001	0.001	0.04
Vaccenic acid (C18:1n-7), %	0.87	0.21	0.001	0.001	0.18
Linoleic acid (C18:2n-6), %	0.33	0.01	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.18	0.04	0.001	0.001	0.003
Arachidic acid (C20:0), %	0.23	0.75	0.41	0.21	0.65
Gadoleic acid (C20:1), %	0.42	0.03	0.67	0.82	0.39
Eicosadienoic acid (C20:2), %	0.19	0.09	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.34	0.001	0.07	0.02	0.69
Other fatty acids, %	0.13	0.55	0.40	0.40	0.28
Total SFA, %[7]	0.44	0.69	0.001	0.001	0.01
Total MUFA, %[8]	0.86	0.02	0.001	0.001	0.06
Total PUFA, %[9]	0.29	0.01	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.04	0.67	0.001	0.001	0.02
UFA:SFA ratio[11]	0.54	0.84	0.001	0.001	0.005
PUFA:SFA ratio[12]	0.31	0.09	0.001	0.001	0.001
Iodine Value, g/100g[13]	0.29	0.34	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 17. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.38	1.32	1.28	1.42	1.30	1.28	0.03
Palmitic acid (C16:0), %	24.64	23.35	21.99	24.67	23.79	22.49	0.30
Palmitoleic acid (C16:1), %	2.46	2.40	2.20	2.56	2.31	2.10	0.10
Margaric acid (C17:0), %	0.52	0.56	0.59	0.52	0.57	0.54	0.03
Stearic acid (C18:0), %	12.80	11.85	10.13	12.88	12.54	11.38	0.38
Oleic acid (C18:1 *cis*-9), %	39.70	37.95	37.19	38.56	38.25	36.02	0.48
Vaccenic acid (C18:1n-7), %	3.72	3.54	3.38	3.71	3.49	3.20	0.09
Linoleic acid (C18:2n-6), %	10.83	14.72	18.63	11.67	13.55	18.59	0.52
α-Linoleic acid (C18:3n-3), %	0.47	0.54	0.63	0.51	0.51	0.60	0.02
Arachidic acid (C20:0), %	0.26	0.26	0.26	0.25	0.28	0.26	0.01
Gadoleic acid (C20:1), %	0.86	0.80	0.82	0.81	0.83	0.75	0.02
Eicosadienoic acid (C20:2), %	0.63	0.79	0.99	0.64	0.76	0.95	0.03
Arachidonic acid (C20:4n-6), %	0.22	0.26	0.27	0.24	0.25	0.27	0.01
Other fatty acids, %	1.52	1.66	1.65	1.57	1.58	1.53	0.05
Total SFA, %	39.85	37.60	34.48	40.01	38.72	36.18	0.62
Total MUFA, %	46.83	44.77	43.66	45.73	44.97	42.15	0.59
Total PUFA, %	12.36	16.56	20.77	13.29	15.29	20.62	0.58
Total *trans* fatty acids, %	0.77	0.88	0.93	0.81	0.81	0.88	0.03
UFA:SFA ratio	1.49	1.64	1.88	1.49	1.56	1.75	0.04
PUFA:SFA ratio	0.31	0.44	0.61	0.34	0.40	0.58	0.02
Iodine value, g/100g	61.0	66.2	72.2	61.6	64.2	70.8	0.87

[1] All values are on a DM basis.
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 18. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 125[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.58	0.89	0.001	0.001	0.33
Palmitic acid (C16:0), %	0.71	0.20	0.001	0.001	0.001
Palmitoleic acid (C16:1), %	0.61	0.74	0.005	0.01	0.06
Margaric acid (C17:0), %	0.46	0.48	0.14	0.05	0.88
Stearic acid (C18:0), %	0.31	0.03	0.001	0.001	0.001
Oleic acid (C18:1 *cis*-9), %	0.22	0.09	0.001	0.001	0.003
Vaccenic acid (C18:1n-7), %	0.66	0.32	0.001	0.001	0.02
Linoleic acid (C18:2n-6), %	0.17	0.78	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.22	0.63	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.64	0.90	0.20	0.20	0.21
Gadoleic acid (C20:1), %	0.15	0.14	0.19	0.13	0.30
Eicosadienoic acid (C20:2), %	0.54	0.40	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.43	0.81	0.003	0.002	0.10
Other fatty acids, %	0.19	0.20	0.31	0.17	0.54
Total SFA, %[7]	0.45	0.05	0.001	0.001	0.001
Total MUFA, %[8]	0.33	0.10	0.001	0.001	0.002
Total PUFA, %[9]	0.18	0.73	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.14	0.29	0.002	0.003	0.06
UFA:SFA ratio[11]	0.34	0.06	0.001	0.001	0.001
PUFA:SFA ratio[12]	0.21	0.34	0.001	0.001	0.001
Iodine value, g/100g[13]	0.28	0.20	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 19. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clear plate fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.36	1.32	1.27	1.31	1.23	1.17	0.03
Palmitic acid (C16:0), %	25.25	23.89	23.04	24.16	23.52	22.26	0.28
Palmitoleic acid (C16:1), %	1.97	1.85	1.75	1.94	1.64	1.60	0.09
Margaric acid (C17:0), %	0.65	0.70	0.74	0.66	0.67	0.70	0.04
Stearic acid (C18:0), %	14.95	13.41	12.43	14.52	14.21	12.30	0.37
Oleic acid (C18:1 *cis*-9), %	36.01	34.29	33.54	35.36	33.47	32.76	0.40
Vaccenic acid (C18:1n-7), %	3.01	2.84	2.72	3.03	2.68	2.62	0.07
Linoleic acid (C18:2n-6), %	12.78	17.24	19.91	14.90	18.18	21.81	0.50
α-Linoleic acid (C18:3n-3), %	0.56	0.64	0.68	0.64	0.67	0.73	0.02
Arachidic acid (C20:0), %	0.27	0.27	0.27	0.24	0.26	0.26	0.01
Gadoleic acid (C20:1), %	0.81	0.78	0.75	0.71	0.74	0.76	0.02
Eicosadienoic acid (C20:2), %	0.68	0.87	0.95	0.73	0.88	1.07	0.03
Arachidonic acid (C20:4n-6), %	0.22	0.25	0.26	0.28	0.30	0.30	0.01
Other fatty acids, %	1.50	1.65	1.70	1.52	1.54	1.67	0.05
Total SFA, %	42.71	39.83	37.98	41.13	40.14	36.93	0.56
Total MUFA, %	41.89	39.82	38.83	41.11	38.60	37.81	0.50
Total PUFA, %	14.43	19.25	22.04	16.74	20.26	24.17	0.54
Total *trans* fatty acids, %	0.82	0.97	1.01	0.90	0.94	1.04	0.03
UFA:SFA ratio	1.32	1.49	1.61	1.42	1.48	1.69	0.04
PUFA:SFA ratio	0.34	0.48	0.58	0.41	0.51	0.66	0.02
Iodine value, g/100g	60.2	66.5	70.4	63.4	67.1	72.9	0.82

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 20. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clear plate fatty acid analysis for pigs harvested at d 107[1]

	Probability, $P<$				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.69	0.003	0.003	0.003	0.10
Palmitic acid (C16:0), %	0.47	0.003	0.001	0.001	0.001
Palmitoleic acid (C16:1), %	0.64	0.09	0.01	0.003	0.46
Margaric acid (C17:0), %	0.85	0.53	0.27	0.18	0.38
Stearic acid (C18:0), %	0.25	0.80	0.001	0.001	0.001
Oleic acid (C18:1 *cis*-9), %	0.98	0.03	0.001	0.001	0.08
Vaccenic acid (C18:1n-7), %	0.40	0.15	0.001	0.001	0.18
Linoleic acid (C18:2n-6), %	0.47	0.001	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.40	0.001	0.001	0.001	0.03
Arachidic acid (C20:0), %	0.54	0.04	0.72	0.42	0.98
Gadoleic acid (C20:1), %	0.11	0.04	0.89	0.73	0.74
Eicosadienoic acid (C20:2), %	0.18	0.02	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.49	0.001	0.02	0.004	0.93
Other fatty acids, %	0.42	0.35	0.01	0.005	0.10
Total SFA, %[7]	0.24	0.11	0.001	0.001	0.001
Total MUFA, %[8]	0.91	0.02	0.001	0.001	0.09
Total PUFA, %[9]	0.46	0.001	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.22	0.26	0.001	0.001	0.03
UFA:SFA ratio[11]	0.33	0.08	0.001	0.001	0.001
PUFA:SFA ratio[12]	0.39	0.001	0.001	0.001	0.001
Iodine value, g/100g[13]	0.26	0.003	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 21. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clear plate fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow			Improvest			
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.32	1.26	1.21	1.34	1.22	1.19	0.03
Palmitic acid (C16:0), %	25.03	23.72	22.41	25.02	23.71	22.50	0.27
Palmitoleic acid (C16:1), %	1.95	1.88	1.63	1.95	1.78	1.47	0.08
Margaric acid (C17:0), %	0.62	0.66	0.72	0.62	0.69	0.67	0.04
Stearic acid (C18:0), %	14.99	13.70	12.15	14.92	14.00	13.04	0.34
Oleic acid (C18:1 *cis*-9), %	36.48	34.57	33.28	35.07	34.96	31.54	0.44
Vaccenic acid (C18:1n-7), %	2.99	2.88	2.63	2.95	2.81	2.42	0.06
Linoleic acid (C18:2n-6), %	12.73	17.08	21.46	14.14	16.60	22.70	0.57
α-Linoleic acid (C18:3n-3), %	0.55	0.61	0.69	0.60	0.60	0.72	0.02
Arachidic acid (C20:0), %	0.25	0.25	0.25	0.25	0.25	0.24	0.01
Gadoleic acid (C20:1), %	0.79	0.77	0.75	0.75	0.77	0.72	0.02
Eicosadienoic acid (C20:2), %	0.67	0.84	1.02	0.70	0.84	1.03	0.03
Arachidonic acid (C20:4n-6), %	0.21	0.24	0.25	0.23	0.24	0.27	0.01
Other fatty acids, %	1.44	1.56	1.56	1.48	1.55	1.49	0.04
Total SFA, %	42.43	39.83	36.95	42.37	40.08	37.88	0.51
Total MUFA, %	42.26	40.16	38.34	40.78	40.39	36.21	0.53
Total PUFA, %	14.33	18.98	23.61	15.84	18.46	24.91	0.62
Total *trans* fatty acids, %	0.81	0.93	0.97	0.87	0.89	0.98	0.03
UFA:SFA ratio	1.34	1.49	1.68	1.34	1.47	1.62	0.03
PUFA:SFA ratio	0.34	0.48	0.64	0.37	0.46	0.66	0.02
Iodine value, g/100g	60.4	66.4	72.6	61.7	65.6	72.9	0.85

[1] All values are on a DM basis.
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

Table 22. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clear plate fatty acid analysis for pigs harvested at d 125[1]

	Probability, *P*<				
	Interaction[2]	Gender[3]	Diet[4]	DDGS[5]	Withdrawal[6]
Myristic acid (C14:0), %	0.41	0.61	0.001	0.001	0.16
Palmitic acid (C16:0), %	0.97	0.92	0.001	0.001	0.001
Palmitoleic acid (C16:1), %	0.57	0.19	0.001	0.001	0.001
Margaric acid (C17:0), %	0.46	0.73	0.11	0.04	0.53
Stearic acid (C18:0), %	0.34	0.17	0.001	0.001	0.001
Oleic acid (C18:1 *cis*-9), %	0.03	0.01	0.001	0.001	0.001
Vaccenic acid (C18:1n-7), %	0.34	0.04	0.001	0.001	0.001
Linoleic acid (C18:2n-6), %	0.18	0.12	0.001	0.001	0.001
α-Linoleic acid (C18:3n-3), %	0.25	0.14	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.92	0.82	0.88	0.76	0.69
Gadoleic acid (C20:1), %	0.67	0.23	0.26	0.41	0.16
Eicosadienoic acid (C20:2), %	0.82	0.53	0.001	0.001	0.001
Arachidonic acid (C20:4n-6), %	0.61	0.20	0.004	0.004	0.07
Other fatty acids, %	0.37	0.67	0.08	0.03	0.48
Total SFA, %[7]	0.61	0.36	0.001	0.001	0.001
Total MUFA, %[8]	0.07	0.01	0.001	0.001	0.001
Total PUFA, %[9]	0.19	0.12	0.001	0.001	0.001
Total *trans* fatty acids, %[10]	0.18	0.62	0.001	0.001	0.02
UFA:SFA ratio[11]	0.61	0.34	0.001	0.001	0.001
PUFA:SFA ratio[12]	0.38	0.46	0.001	0.001	0.001
Iodine Value, g/100g[13]	0.46	0.64	0.001	0.001	0.001

[1] All values are on a DM basis.
[2] Interaction gender × diet type.
[3] Main effect of gender (Treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).
[4] Main effect of diet type (corn-soy or 30% DDGS).
[5] Effect of DDGS before d 74 (Treatments 1 and 4 vs. 2, 3, 5, and 6).
[6] Effect of DDGS withdrawal after d 74 (Treatments 2 and 5 vs. 3 and 6).
[7] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[8] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[9] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[10] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[11] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[12] PUFA:SFA = total PUFA/total SFA.
[13] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 23. Effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on fatty acid concentrations for pigs harvested at d 107[1,2]

	Jowl			Belly			Backfat			Clear plate		
	Gender[3]	DDGS[4]	Withdraw[5]	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw
Myristic acid (C14:0)	↓	↓	~	↓	↓	↓*	↓	↓	~	↓	↓	↓*
Palmitic acid (C16:0)	↓*	↓	↓*	~	↓	↓	↓	↓	↓	↓	↓	↓
Palmitoleic acid (C16:1)	~	↓	~	~	↓	~	~	↓	~	↓*	↓	~
Margaric acid (C17:0)	~	↑	~	~	~	~	~	~	~	~	~	~
Stearic acid (C18:0)	~	↓	↓	↑*	↓	↓	~	↓	↓	~	↓	↓
Oleic acid (C18:1 *cis*-9)	↓	↓	↓*	↓	↓	↓	↓	↓	↓	↓	↓	↓*
Vaccenic acid (C18:1n-7)	~	↓	~	~	↓	~	~	↓	↓	~	↓	~
Linoleic acid (C18:2n-6)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
α-Linoleic acid (C18:3n-3)	↑	↑	~	↑	↑	↑	↑	↑	↑	↑	↑	↑
Arachidic acid (C20:0)	↓*	~	~	~	~	~	~	~	~	↓	~	~
Gadoleic acid (C20:1)	↓	~	~	↓	~	~	↓	~	~	↓	~	~
Eicosadienoic acid (C20:2)	↑	↑	↑	↑*	↑	↑	~	↑	↑	↑	↑	↑
Arachidonic acid (C20:4n-6)	↑	↑	~	↑	↑	~	↑*	↑*	~	↑	↑	~
Other fatty acids	~	↑	↑	~	~	~	~	↑	↑*	~	↑	↑*
Total SFA[6]	~	↓	↓	~	↓	↓	~	↓	↓	~	↓	↓
Total MUFA[7]	↓	↓	↓*	↓	↓	↓*	↓	↓	↓	↓	↓	↓*
Total PUFA[8]	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Total *trans* fatty acids[9]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
UFA:SFA ratio[10]	~	↑	↑	~	↑	↑	~	↑	↑	↑*	↑	↑
PUFA:SFA ratio[11]	↑	↑	↑	↑*	↑	↑	↑	↑	↑	↑	↑	↑
Iodine value, g/100g[12]	↑*	↑	↑	~	↑	↑	↑	↑	↑	↑	↑	↑

[1] Symbols (↓↑) mean significant differences ($P < 0.05$); symbols with (*) mean trend ($P < 0.10$); ~ means no difference ($P > 0.10$).
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Effect of gender (Immunocastrate vs. Barrow); ↑ means value was higher for IC pigs; ↓ means value was lower for IC pigs.
[4] Effect of DDGS for first 74 d; ↑ means value was higher for pigs fed DDGS; ↓ means value was lower for pigs fed DDGS.
[5] Effect of DDGS during withdrawal; ↑ means value was higher for pigs fed DDGS throughout; ↓ means value was lower for pigs fed DDGS throughout.
[6] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[7] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[8] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[9] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[10] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[11] PUFA:SFA = total PUFA/total SFA.
[12] Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 24. Effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on fatty acid concentrations for pigs harvested at d 125[1,2]

	Jowl			Belly			Backfat			Clear plate		
	Gender[3]	DDGS[4]	Withdraw[5]	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw
Myristic acid (C14:0)	~	↓	~	~	↓	~	~	↓	~	~	↓	~
Palmitic acid (C16:0)	~	↓	~	~	↓	↓	~	↓	↓	~	↓	↓
Palmitoleic acid (C16:1)	~	↓	↓	~	↓	↓*	~	↓	↓	~	↓	↓
Margaric acid (C17:0)	~	~	~	~	↑	~	~	↑	~	~	↑	~
Stearic acid (C18:0)	↑	↓	~	↑	↓	↓	↑	↓	↓	~	↓	↓
Oleic acid (C18:1 *cis*-9)	↓	↓	↓	↓*	↓	↓	~	↓	↓	↓	↓	↓
Vaccenic acid (C18:1n-7)	↓	↓	↓	~	↓	↓	↓*	↓	↓	↓	↓	↓
Linoleic acid (C18:2n-6)	↑	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
α-Linoleic acid (C18:3n-3)	↑*	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Arachidic acid (C20:0)	~	~	~	~	~	~	~	~	↓	~	~	~
Gadoleic acid (C20:1)	~	↓	~	~	~	~	~	↓	↓	~	~	~
Eicosadienoic acid (C20:2)	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Arachidonic acid (C20:4n-6)	~	↑	~	~	↑	↑*	~	↑	↑*	~	↑	↑*
Other fatty acids	↓*	↑	~	~	~	~	↓	↑	~	~	↑	~
Total SFA[6]	~	↓	↓*	↑	↓	↓	↑	↓	↓	~	↓	↓
Total MUFA[7]	↓	↓	↓	↓*	↓	↓	↓*	↓	↓	↓	↓	↓
Total PUFA[8]	↑	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Total *trans* fatty acids[9]	~	↑	~	~	↑	↑*	~	↑	↑	~	↑	↑
UFA:SFA ratio[10]	~	↑	↑	↓*	↑	↑	↓	↑	↑	~	↑	↑
PUFA:SFA ratio[11]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Iodine value, g/100g[12]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑

[1] Symbols (↓↑) mean significant differences ($P < 0.05$); symbols with (*) mean trend ($P < 0.10$); ~ means no difference ($P > 0.10$).
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Effect of gender (Immunocastrate vs. Barrow); ↑ means value was higher for IC pigs; ↓ means value was lower for IC pigs.
[4] Effect of DDGS for first 74 d; ↑ means value was higher for pigs fed DDGS; ↓ means value was lower for pigs fed DDGS.
[5] Effect of DDGS during withdrawal; ↑ means value was higher for pigs fed DDGS throughout; ↓ means value was lower for pigs fed DDGS throughout.
[6] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[7] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[8] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[9] Total *trans* fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.
[10] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[11] PUFA:SFA = total PUFA/total SFA.
[12] Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

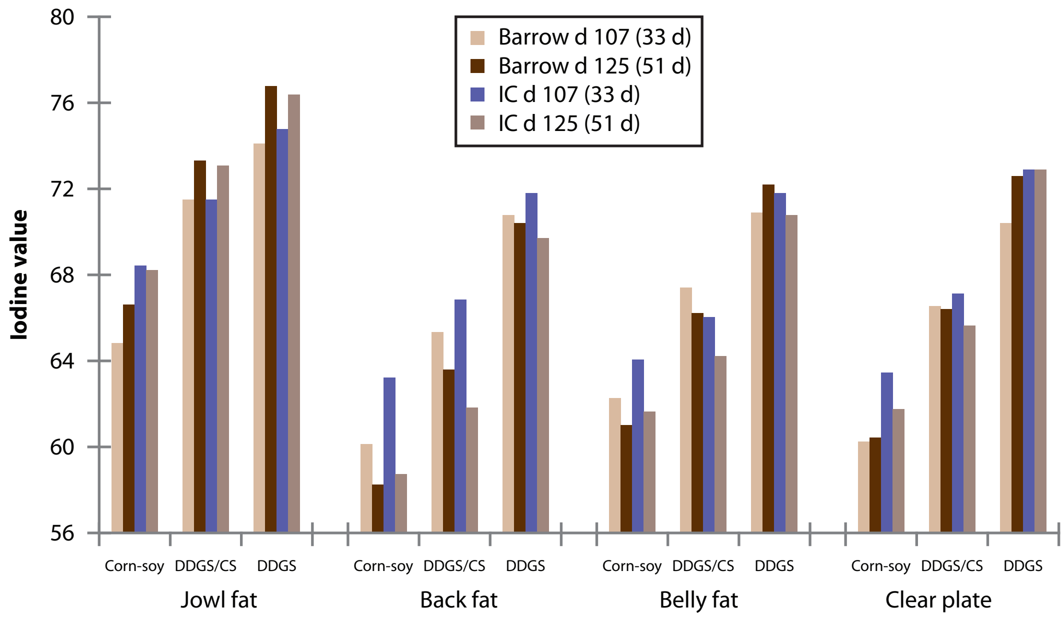

Figure 1. Differences in fat depot iodine values and changes between genders and time post–second injection.

The Interactive Effects of High-Fiber Diets and Ractopamine HCl on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality, and Intestinal Weights[1]

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Summary

In previous research, feeding pigs high amounts of dried distillers grains with solubles (DDGS) and wheat middlings (midds) has been shown to reduce carcass yield and negatively affect iodine value (IV). The influence of Ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN) on this response is not known; therefore, a total of 575 finishing pigs (PIC 327 × 1050, initially 123 lb) were used in two consecutive 73-d trials to determine the effects of DDGS and midds (high fiber) withdrawal 24 d before harvest in diets with or without RAC on finishing pig growth performance, carcass characteristics, and fat quality. From d 0 to 49, pigs were allotted to 1 of 2 dietary treatments in a completely randomized design based on initial pen weight. The dietary treatments included a corn-soybean meal–based control diet or diets with 30% DDGS and 19% wheat midds. Twelve pens of pigs were fed the corn-soybean meal control diet, and 24 pens were fed the high-fiber diet. During this 49 d period, pigs fed the corn-soybean meal diets had improved ($P < 0.0001$) ADG and F/G compared with those fed the high-fiber diets.

On d 49, pens of pigs were re-allotted to 1 of 6 dietary treatments; pigs remained on the corn-soybean meal diets, switched from the high-fiber diet to corn-soybean meal (withdrawal diet), or were maintained on the high-fiber diet. These 3 regimens were fed with or without 9 g/ton RAC.

No fiber withdrawal regimen × RAC interactions were observed ($P > 0.10$). Pigs maintained on the corn-soybean meal diet or switched to the withdrawal diet had greater ($P < 0.02$) ADG and better F/G than those that remained on the high-fiber diet throughout the study.

Overall (d 0 to 73), pigs fed the corn-soybean meal diet throughout had greater ($P < 0.03$) ADG and better F/G than those fed the high-fiber withdrawal regimen and the high-fiber diets throughout. Pigs fed the withdrawal diet had greater ($P < 0.03$) ADG and ADFI but F/G similar to those fed high-fiber diets throughout. Pigs fed RAC had increased ($P < 0.0002$) ADG, final BW, and improved F/G regardless of dietary regimen.

[1] Appreciation is expressed to Roger Johnson and Cory Rains at Farmland Foods LLC, Crete, NE, for assistance in carcass data collection.

[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

For carcass characteristics, pigs fed the corn-soybean meal diet throughout had greater ($P < 0.001$) carcass yield compared with the pigs fed the high-fiber diet throughout, with those fed the withdrawal diets being intermediate. Pigs fed RAC had greater ($P < 0.001$) carcass yield than those not fed RAC. Iodine values of jowl, backfat, belly, and leaf fat were lowest ($P < 0.001$) for pigs fed the corn soybean meal diets, highest ($P < 0.01$) for those fed high-fiber diets throughout (due to DDGS and midds), and intermediate for pigs fed the high-fiber withdrawal diet. Feeding RAC increased ($P < 0.04$) IV of backfat, but did not influence IV of other fat depots. We observed no differences in intestine and organ weights between pigs that were fed corn-soybean meal diets for the duration of the study and pigs that were switched to the corn-soybean meal from high fiber at d 49; however, pigs that remained on the high-fiber diets throughout the study had increased ($P < 0.05$) full cecum and large intestine weights compared with the pigs that were switched from high-fiber diets to the corn-soybean meal diets at d 49.

Feeding the high-fiber diets containing DDGS and midds throughout the study decreased growth performance and carcass yield and increased IV compared with those fed a corn-soybean meal diet. Withdrawing the high-fiber diet and switching to a corn-soybean meal diet for the last 24 d before harvest partially or completely mitigated these negative effects. Feeding RAC for the last 24 d before market, regardless of dietary regimen, improved growth performance and increased carcass yield.

Key words: corn, DDGS, fiber, finishing pig, Ractopamine HCl, wheat middlings

Introduction

By-product ingredients such as dried distillers grains with solubles (DDGS) and wheat middlings are common feed ingredients used in diet formulation. A major concern with feeding a high amount of DDGS is soft carcass fat (high iodine value) and both DDGS and midds have been shown to reduce carcass yield. Complete withdrawal of DDGS and wheat midds before marketing has been successful in lowering the iodine value (IV) and improving carcass yield.[3]

A feed additive that improves carcass yield is Ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN). It is frequently added to finishing swine diets the last 3 wk before marketing to increase weight gain and improve F/G. The supplement also has positive effects on carcass yield, so in addition to feeding a withdrawal diet before marketing, feeding RAC may also reverse or mitigate the negative effects of high-fiber diets on carcass yield. The objective of this study was to determine the effects of RAC on growth performance, carcass characteristics, carcass fat quality, and intestinal weights of pigs withdrawn from the high-fiber diets before market vs. pigs fed corn-soybean meal based diets or high-fiber diets containing DDGS and midds.

Procedures

The protocols for these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

[3] Asmus et al., Swine Day 2011, Report of Progress 1056, pp. 202.

These studies were conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (8 ft × 10 ft). The pens had adjustable gates facing the alleyway that allowed for 10 ft^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

Wheat midds and DDGS samples were collected at the time of feed manufacture, and a composite sample was analyzed at Ward Laboratories (Kearney, NE; Table 1). Fatty acid analyses were conducted on the DDGS and midds used in the study at the K-State Analytical Lab (Manhattan, KS; Table 2). Feed samples were also collected from each feeder during each phase and combined for a single composite sample by treatment for each phase to measure bulk density (Table 3). Bulk density of a material represents the mass per unit volume (lb/bushel).

A total of 575 pigs (PIC 327 × 1050, initially 123 lb) were used in two consecutive studies (73 and 72 d, respectively). Initially, pens of pigs (4 barrows and 4 gilts per pen) were randomly allotted by initial weight to 1 of 2 dietary treatments in a completely randomized design based on initial pen weight. The dietary treatments included a corn-soybean meal–based control diet or diets with 30% DDGS and 19% midds (Table 3). Twelve pens of pigs were fed the corn-soybean meal control diet, and 24 pens were fed the high-fiber diet. On d 49, pigs were re-allotted to 1 of 6 treatments. Pens of pigs previously fed the corn-soybean meal–based diets remained on corn-soybean meal diets with or without the addition of RAC (Tables 4 and 5). Half of the high fiber–fed pigs were switched to corn-soybean meal–based diets, which served as the high-fiber withdrawal treatment, again with or without RAC. Finally, half of the high-fiber diet–fed pigs remained on a high-fiber diet with or without RAC. There were 12 replications per treatment.

Pigs and feeders were weighed approximately every 3 wk to calculate ADG, ADFI, and F/G. In the first trial, before marketing, all pigs were weighed individually to allow for calculation of carcass yield. The second heaviest barrow in each pen (1 pig per pen, 6 pigs per treatment) was identified to be harvested at the K-State Meats Lab. Hot carcass weights were measured immediately after evisceration. Following evisceration, the entire pluck (heart, lungs, liver, kidneys, spleen, stomach, cecum, large intestine and small intestine) was weighed, then the individual organs were weighed. After full organ weights were recorded, the large intestine, stomach, and cecum were physically stripped, flushed with water, and weighed again. After carcasses had chilled, 10^{th}-rib backfat and loin eye area measurements were taken. Because there were differences in HCW, it was used as a covariate for backfat and loin depth. In the second trial, all pigs were transported approximately 2 h to Farmland Foods (Crete, NE). Pigs harvested at the commercial packing plant were individually tattooed to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration, and belly and jowl fat samples were collected from each carcass and analyzed for their fatty acid content. Percentage yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of diet type, high-fiber diet withdrawal time, and RAC usage and their interactions were tested. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and Discussion

As expected, adding 30% DDGS and 19% midds decreased diet bulk density (Table 3).

No interactions were found ($P > 0.10$) between fiber withdrawal regimen and RAC for any response criteria. From d 0 to 49, pigs fed the corn-soybean meal–based diet had increased ($P < 0.001$) ADG and improved F/G compared with pigs fed the high-fiber diet (Table 6).

From d 49 to 73, pigs maintained on the corn-soybean meal diet or those switched to the corn-soybean meal diet on d 49 had similar ADG and F/G, and both were improved ($P < 0.03$) compared with pigs maintained on high fiber throughout. Pigs fed RAC had increased ($P < 0.0001$) ADG and improved F/G compared with those not fed RAC. Pigs that remained on high fiber had decreased ($P = 0.0002$) final BW compared with those maintained on the corn-soybean meal diets throughout or switched from high fiber to the corn-soybean meal diet (fiber withdrawal).

Pigs fed high-fiber diets throughout had decreased ($P < 0.001$) carcass yield and carcass weight compared with pigs fed corn-soybean meal diets for the entire study, whereas pigs that were switched from high-fiber diets to corn-soybean meal diets on d 49 were intermediate ($P = 0.01$). Pigs fed RAC had increased ($P < 0.001$) carcass yield and carcass weight compared with pigs that were not fed RAC. No differences ($P > 0.15$) were observed in 10th-rib fat depth or loin eye area among the different dietary fiber regimens; however, RAC tended to decrease ($P < 0.10$) backfat.

No differences were observed in intestine and organ weights between pigs that were fed corn-soybean meal diets for the duration of the study and pigs switched to the corn-soybean meal from high fiber at d 49 (Table 7); however, pigs that remained on the high-fiber diets throughout the study had increased ($P < 0.05$) full cecum and large intestine weights compared with the pigs switched from high-fiber diets to the corn-soybean meal diets at d 49. These results correspond to previous data in which high-fiber diets increased intestine weights.[3] Pigs fed RAC had decreased ($P = 0.01$) rinsed stomach weight and tended to have decreased ($P = 0.07$) full stomach weight compared with pigs that were not fed RAC. Kidney fat decreased ($P = 0.02$) in pigs that were fed the high-fiber diets throughout.

Pigs fed high fiber throughout had increased ($P = 0.02$) linoleic (C18:2n-6) and eicosadienoic (C20:2) concentrations in backfat, belly, leaf, and jowl fat (Tables 8 through 11). Iodine value was lowest ($P < 0.001$) in all 4 fat depots for pigs fed the corn-soybean meal diet throughout and highest ($P < 0.01$) for those fed high fiber throughout, with those on the fiber withdrawal regimen being intermediate. Added RAC had no effect ($P > 0.12$) on jowl, leaf, or belly fat IV but increased ($P < 0.05$) IV in backfat.

Pigs fed RAC the last 24 d before harvest had improved ADG, ADFI, and F/G as well as carcass yield, regardless of fiber withdrawal regimen. Feeding high-fiber diets throughout the study decreased growth performance, increased full intestine weight, decreased carcass yield, and increased carcass fat IV compared with those fed a corn-soybean meal diet. Withdrawing the high-fiber diet and switching to a corn-soybean meal diet for the last 24 d before harvest restored carcass yield to values similar to pigs fed corn-soybean meal–based diets but only partially mitigated the negative effects on carcass fat IV.

Table 1. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (as-fed basis)[1]

Nutrient,%	DDGS	Wheat middlings
DM	92.2	90.8
CP	29.2	17.5
Fat (oil)	9.3	4.3
Crude fiber	7.7	8.4
ADF	12.1	13.3
NDF	28.7	34.9
Ash	6.5	5.6

[1] Values represent the mean of a composite sample among the 2 trials.

Table 2. Fatty acid analysis of dietary ingredients[1]

	Exp. 1		Exp. 2	
Item	DDGS[2]	Wheat midds	DDGS	Wheat midds
Myristic acid (C14:0), %	0.05	0.11	0.06	0.10
Palmitic acid (C16:0), %	13.71	15.62	13.64	15.42
Palmitoleic acid (C16:1), %	0.17	0.21	0.16	0.19
Margaric acid (C17:0), %	0.15	0.28	0.14	0.29
Stearic acid (C18:0), %	2.16	1.02	2.08	1.14
Oleic acid (C18:1 cis-9), %	25.22	16.62	24.75	16.33
Vaccenic acid (C18:1n-7), %	1.23	1.53	1.22	1.40
Linoleic acid (C18:2n-6), %	54.06	56.74	54.59	56.87
α-Linoleic acid (C18:3n-3), %	1.53	4.20	1.58	4.26
Arachidic acid (C20:0), %	0.43	0.26	0.42	0.24
Gadoleic acid (C20:1), %	0.25	0.70	0.24	0.71
Eicosadienoic acid (C20:2), %	0.08	0.14	0.09	0.14
Arachidonic acid (C20:4n-6), %	0.04	0.06	0.04	0.06
Other fatty acids, %	0.87	2.58	1.00	2.79
Total SFA, %[3]	16.50	17.29	16.33	17.19
Total MUFA, %[4]	27.11	19.25	26.55	18.83
Total PUFA, %[5]	55.71	61.13	56.30	61.33
Total trans fatty acids, %[6]	0.08	0.00	0.10	0.06
UFA:SFA ratio[7]	5.02	4.65	5.07	4.66
PUFA:SFA ratio[8]	3.38	3.54	3.45	3.57
Iodine value, g/100g[9]	119.68	124.29	120.30	124.43

[1] Values represent the mean of 4 samples collected during each trial.
[2] DDGS: dried distillers grains with solubles.
[3] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] +[C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.
[4] Total MUFA = ([C14:1] + [C16:1] + [C18:1 cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.
[5] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.
[6] Total *trans* fatty acids = ([C18:1 trans] + [C18:2 trans] + [C18:3 trans]); brackets indicate concentration.
[7] UFA:SFA = (total MUFA + total PUFA)/total SFA.
[8] PUFA:SFA = total PUFA/total SFA.
[9] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785; brackets indicate concentration.

Table 3. Bulk density of experimental diets (as-fed basis)[1]

		Treatments	
	DDGS,%:[2]	None	30
Bulk density, lb/bu[3]	Wheat midds,%:	None	19
Phase 1		56.22	43.02
Phase 2		53.42	40.87
Phase 3		57.72	42.78
Phase 4		56.64	44.71

[1] Diet samples collected from each feeder during each phase.
[2] DDGS: dried distillers grains with solubles.
[3] Phase 1 was d 0 to 7; Phase 2 was d 7 to 28; Phase 3 was d 28 to 49; Phase 4 was d 49 to 73.

Table 4. Phase 1 and 2 diets (as-fed basis)[1]

	Phase 1		Phase 2	
Item	Corn-soy	High fiber	Corn-soy	High fiber
Ingredient, %				
Corn	79.0	40.0	82.7	43.6
Soybean meal, 46.5% CP	18.9	8.7	15.3	5.2
DDGS[2]	---	30.0	---	30.0
Wheat middlings	---	19.0	---	19.0
Monocalcium P, 21% P	0.35	---	0.25	---
Limestone	1.00	1.28	0.98	1.29
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.10	0.10
Trace mineral premix	0.13	0.13	0.10	0.10
L-lysine HCl	0.15	0.29	0.14	0.28
DL-methionine	---	---	---	---
L-threonine	0.01	---	---	---
Phytase 600[3]	0.13	0.13	0.13	0.13
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standard ileal digestible (SID) amino acids, %				
Lysine, %	0.79	0.79	0.69	0.69
Isoleucine:lysine	70	74	72	76
Methionine:lysine	30	37	32	41
Met & Cys:lysine	62	77	66	83
Threonine:lysine	63	69	64	72
Tryptophan:lysine	19	19	19	19
Valine:lysine	81	94	85	99
Total lysine, %	0.89	0.94	0.78	0.83
ME, kcal/lb	1,516	1,486	1,520	1,487
SID lysine:ME ratio, g/Mcal	2.36	2.41	2.06	2.10
CP, %	15.6	18.9	14.3	17.6
Crude fiber, %	2.5	4.9	2.4	4.8
NDF	9.3	19.0	9.3	19.0
ADF	3.2	6.6	3.1	6.5
Ca, %	0.53	0.56	0.49	0.55
P, %	0.42	0.56	0.39	0.55
Available P, %	0.13	0.27	0.11	0.26

[1] Phase 1 was d 0 to 28; Phase 2 was d 28 to 49.
[2] DDGS: dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

Table 5. Phase 3 diets (as-fed basis)[1]

	Phase 3			
	Corn-soy		High fiber	
Item RAC:[2]	-	+	-	+
Ingredient, %				
Corn	85.0	75.3	45.7	35.9
Soybean meal, 46.5% CP	13.2	22.7	3.1	12.7
DDGS[3]	---	---	30.0	30.0
Wheat middlings	---	---	19.0	19.0
Monocalcium P, 21% P	0.20	0.15	---	---
Limestone	0.93	0.90	1.40	1.40
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08
L-lysine HCl	0.13	0.17	0.27	0.31
DL-methionine	---	0.02	---	---
L-threonine	0.01	0.06	---	---
Paylean, 9 g/lb[4]	---	0.05	---	0.05
Phytase 600[5]	0.125	0.125	0.125	0.125
Total	100	100	100.00	100.00
Calculated analysis				
Standard ileal digestible (SID) amino acids, %				
Lysine, %	0.63	0.90	0.63	0.90
Isoleucine:lysine	73	69	78	72
Methionine:lysine	33	30	43	35
Met & Cys:lysine	69	60	88	72
Threonine:lysine	67	67	74	67
Tryptophan:lysine	19	19	19	19
Valine:lysine	87	79	1	89
Total lysine, %	0.72	1.01	0.77	1.06
ME, kcal/lb	1,522	1,521	1,486	1,484
SID lysine:ME ratio, g/Mcal	1.88	2.68	1.92	2.75
CP, %	13.5	17.2	16.7	20.4
Crude fiber, %	2.4	2.5	4.8	4.9
NDF	9.3	9.3	19.0	18.9
ADF	3.1	3.3	6.4	6.7
Ca, %	0.46	0.47	0.59	0.62
P, %	0.37	0.40	0.54	0.58
Available P, %	0.10	0.10	0.26	0.27

[1] Phase 3 was d 49 to 73.
[2] Ractopamine HCl (RAC; Paylean, Elanco Animal Health, Greenfield, IN)
[3] DDGS: dried distillers grains with solubles.
[4] Paylean, 9 g/lb, was added at a rate of 1 lb/ton.
[5] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO.) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

Table 6. Effects of high fiber with or without ractopamine HCl (RAC[1]) on growth performance and carcass characteristics[2]

Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber						
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
d 0 to 49												
ADG, lb	2.24	2.22	2.11	2.11	2.10	2.11	0.08	<0.001	-	-	-	-
ADFI, lb	6.14	6.05	5.99	6.10	5.92	5.90	0.10	0.13	-	-	-	-
F/G	2.75	2.73	2.85	2.89	2.83	2.80	0.07	0.001	-	-	-	-
d 49 to 73												
ADG, lb	2.00	2.40	2.03	2.46	1.89	2.19	0.20	0.32	0.46	0.02	0.002	<0.001
ADFI, lb	6.94	6.70	7.29	7.16	6.98	6.85	0.30	0.02	0.002	0.44	0.02	0.11
F/G	3.56	2.80	3.61	2.93	3.72	3.17	0.18	0.01	0.22	0.001	0.01	<0.001
Overall												
ADG, lb	2.16	2.27	2.08	2.22	2.03	2.13	0.12	0.001	0.03	<0.001	0.01	<0.001
ADFI, lb	6.40	6.26	6.41	6.44	6.26	6.21	0.16	0.951	0.23	0.279	0.03	0.42
F/G	2.98	2.76	3.08	2.90	3.09	2.92	0.10	<0.001	<0.001	<0.001	0.64	<0.001
BW, lb												
d 0	122.7	122.7	123.0	123.0	123.3	123.3	6.24	0.73	0.84	0.70	0.85	0.99
d 49	232.2	231.5	226.9	226.6	226.2	226.6	3.29	0.01	0.03	0.02	0.89	0.91
d 73	279.3	287.5	275.7	284.9	270.8	278.1	3.91	0.01	0.23	0.001	0.03	0.001

continued

Table 6. Effects of high fiber with or without ractopamine HCl (RAC[1]) on growth performance and carcass characteristics[2]

Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
Item RAC:	-	+	-	+	-	+	SEM					
Carcass traits												
HCW, lb[8]	203.2	215.3	201.3	210.5	195.0	201.4	2.76	0.001	0.22	<0.001	0.01	<0.001
Yield, %[8]	74.22	75.13	73.73	74.58	72.77	73.61	0.19	< 0.001	0.01	< 0.001	< 0.001	< 0.001
Avg BF[9]	1.11	1.02	1.04	0.94	0.94	0.97	0.06	0.04	0.13	0.05	0.49	0.21
LEA[9]	7.68	8.05	7.99	8.61	7.96	7.90	0.34	0.36	0.15	0.84	0.24	0.23

[1] Paylean; Elanco Animal Health (Greenfield, IN).
[2] A total of 575 pigs (PIC 327 ×1050, initially 123 lb BW) were used in a 73-d growth trial with 8 pigs per pen and 12 replications per treatment. No fiber withdrawal × RAC interactions were observed.
[3] Treatments A, B vs. C, D, E, F.
[4] Treatments A, B vs. C, D.
[5] Treatments A, B vs. E, F.
[6] Treatments C, D vs. E, F.
[7] Treatments A, C, E vs. B, D, F.
[8] Values represent 278 observations from pigs that were shipped approximately 2 h to Farmland Foods (Crete, NE).
[9] Values represent 36 barrows (6 observations per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS).

Table 7. Effects of high fiber with or without Ractopamine HCl (RAC[1]) on intestine and organ weights[2]

Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
Item RAC:	-	+	-	+	-	+	SEM					
Whole intestine	17.99	19.13	18.19	19.13	20.39	19.64	1.00	0.38	0.92	0.16	0.18	0.59
Stomach												
Full	2.30	2.51	2.84	1.98	2.68	2.20	0.24	0.92	0.97	0.89	0.92	0.07
Rinsed	1.58	1.54	1.66	1.48	1.71	1.55	0.05	0.34	0.80	0.16	0.25	0.01
Cecum												
Full	1.39	1.52	1.73	1.60	1.72	2.02	0.20	0.08	0.30	0.05	0.33	0.56
Rinsed	0.72	0.76	0.78	0.75	0.66	0.68	0.04	0.58	0.45	0.09	0.02	0.72
Large intestine												
Full	9.64	9.48	9.33	10.22	11.92	11.82	0.65	0.03	0.74	0.001	0.003	0.70
Rinsed	4.42	4.19	4.33	4.41	4.17	4.38	0.20	0.93	0.76	0.87	0.64	0.89
Small intestine												
Full	7.43	7.92	7.65	7.42	8.01	6.82	0.48	0.63	0.77	0.58	0.80	0.42
Heart	1.00	0.95	1.00	0.93	0.93	1.00	0.04	0.66	0.70	0.70	1.00	0.59
Liver	4.52	4.33	4.59	4.70	4.67	4.64	0.15	0.09	0.15	0.14	0.96	0.77
Kidneys	1.03	1.03	1.03	1.00	1.00	1.13	0.04	0.77	0.74	0.41	0.25	0.38
Kidney Fat	3.97	3.83	3.56	3.21	3.07	2.85	0.37	0.03	0.17	0.02	0.25	0.43

[1] Paylean; Elanco Animal Health (Greenfield, IN).

[2] A total of 575 pigs (PIC 327 ×1050, initially 123 lb BW) were used in a 73-d growth trial with 8 pigs per pen and 12 replications per treatment. Values represent 36 barrows (6 observations per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS). No fiber withdrawal × RAC interactions were observed.

[3] Treatments A, B vs. C, D, E, F.

[4] Treatments A, B vs. C, D.

[5] Treatments A, B vs. E, F.

[6] Treatments C, D vs. E, F.

[7] Treatments A, C, E vs. B, D, F.

Table 8. Effects of high fiber with or without Ractopamine HCl (RAC[1]) on fatty acid analysis of jowl fat samples[2]

Item	Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
	d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
	d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber						
	RAC:	-	+	-	+	-	+	SEM	Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
Myristic acid (C14:0), %		1.37	1.34	1.40	1.31	1.30	1.33	0.04	0.53	0.98	0.29	0.32	0.32
Palmitic acid (C16:0), %		23.10	23.24	22.21	21.81	21.31	21.23	0.32	<.001	0.001	0.001	0.02	0.64
Palmitoleic acid (C16:1), %		3.55	3.70	3.48	3.17	3.26	3.10	0.13	0.001	0.02	0.001	0.23	0.28
Stearic acid (C18:0), %		9.20	9.28	8.87	8.97	8.49	8.63	0.25	0.02	0.19	0.01	0.14	0.59
Oleic acid (C18:1 cis-9), %		48.50	48.59	45.24	45.67	44.02	42.74	0.79	<.001	0.001	0.001	0.01	0.67
Vaccenic acid (C18:1n-7), %		0.23	0.18	0.20	0.24	0.20	0.20	0.04	0.88	0.65	0.84	0.52	0.93
Linoleic acid (C18:2n-6), %		10.31	9.64	14.24	14.54	16.56	17.63	0.67	<.001	0.001	0.001	0.001	0.65
α-Linoleic acid (C18:3n-3), %		0.46	0.52	0.61	0.60	0.70	0.76	0.03	<.001	0.001	0.001	0.001	0.11
Arachidic acid (C20:0), %		0.21	0.21	0.17	0.20	0.21	0.24	0.02	0.92	0.32	0.39	0.07	0.16
Gadoleic acid (C20:1), %		1.03	0.97	0.87	1.02	0.91	0.97	0.06	0.24	0.34	0.29	0.93	0.30
Eicosadienoic acid (C20:2), %		0.53	0.49	0.66	0.77	0.77	0.84	0.04	<.001	.0001	0.001	0.02	0.13
Arachidonic acid (C20:4n-6), %		0.20	0.22	0.25	0.22	0.26	0.29	0.02	0.004	0.14	0.001	0.03	0.59
Other fatty acids, %		1.33	1.64	1.81	1.48	2.01	2.05	0.23	0.07	0.47	0.02	0.09	0.97
Iodine value, g/100g[8]		65.14	64.28	69.31	70.04	72.35	73.15	0.86	<.001	0.001	0.001	0.001	0.74

[1] Paylean; Elanco Animal Health (Greenfield, IN).
[2] Values represent 36 barrows (6 per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS). All values are on a DM basis. No fiber withdrawal × RAC interactions were observed.
[3] Treatments A, B vs. C, D, E, F.
[4] Treatments A, B vs. C, D.
[5] Treatments A, B vs. E, F.
[6] Treatments C, D vs. E, F.
[7] Treatments A, C, E vs. B, D, F.
[8] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 9. Effects of high fiber with or without Ractopamine HCl (RAC[1]) on fatty acid analysis of backfat samples[2]

Item	Treatment: A	B	C	D	E	F	SEM	d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
RAC:	-	+	-	+	-	+						
Myristic acid (C14:0), %	1.37	1.35	1.39	1.27	1.34	1.22	0.06	0.27	0.57	0.18	0.43	0.10
Palmitic acid (C16:0), %	23.87	23.28	22.62	21.99	22.07	20.93	0.59	0.003	0.04	0.001	0.18	0.11
Palmitoleic acid (C16:1), %	2.87	3.03	2.68	2.49	2.45	2.34	0.12	0.001	0.005	0.001	0.13	0.65
Stearic acid (C18:0), %	10.86	9.92	10.15	9.64	10.10	9.04	0.60	0.21	0.41	0.17	0.59	0.09
Oleic acid (C18:1 cis-9), %	45.84	45.64	41.10	42.36	39.02	39.31	0.79	<.001	0.001	0.001	0.003	0.49
Vaccenic acid (C18:1n-7), %	0.21	0.21	0.28	0.04	0.13	0.14	0.06	0.20	0.35	0.19	0.72	0.09
Linoleic acid (C18:2n-6), %	11.23	12.56	17.11	17.92	20.25	22.07	0.82	<.001	0.001	0.001	0.001	0.05
α-Linoleic acid (C18:3n-3), %	0.53	0.63	0.72	0.76	0.77	0.85	0.04	<.001	0.001	0.001	0.09	0.02
Arachidic acid (C20:0), %	0.25	0.23	0.27	0.15	0.25	0.24	0.05	0.83	0.55	0.82	0.40	0.20
Gadoleic acid (C20:1), %	0.92	0.87	0.79	0.91	0.79	0.80	0.05	0.07	0.29	0.04	0.28	0.46
Eicosadienoic acid (C20:2), %	0.50	0.56	0.69	0.75	0.79	0.86	0.04	<.001	0.001	0.001	0.02	0.09
Arachidonic acid (C20:4n-6), %	0.21	0.34	0.36	0.28	0.34	0.37	0.05	0.14	0.35	0.10	0.46	0.48
Other fatty acids, %	1.34	1.38	1.86	1.45	1.70	1.84	0.18	0.04	0.12	0.03	0.54	0.61
Iodine value, g/100g[8]	63.87	66.39	70.27	72.56	73.70	77.22	1.59	<.001	0.001	0.001	0.01	0.04

[1] Paylean; Elanco Animal Health (Greenfield, IN).
[2] Values represent 36 barrows (6 per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS). All values are on a DM basis. No fiber withdrawal × RAC interactions were observed.
[3] Treatments A, B vs. C, D, E, F.
[4] Treatments A, B vs. C, D.
[5] Treatments A, B vs. E, F.
[6] Treatments C, D vs. E, F.
[7] Treatments A, C, E vs. B, D, F.
[8] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 10. Effects of high fiber with or without Ractopamine HCl (RAC[1]) on fatty acid analysis of belly fat samples[2]

Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber						
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
Myristic acid (C14:0), %	1.52	1.46	1.51	1.41	1.41	1.39	0.06	0.24	0.64	0.12	0.27	0.18
Palmitic acid (C16:0), %	25.60	25.21	24.71	24.25	22.63	22.09	0.62	0.001	0.15	0.001	0.002	0.37
Palmitoleic acid (C16:1), %	3.34	3.34	3.03	2.67	3.12	2.91	0.22	0.04	0.03	0.15	0.47	0.30
Stearic acid (C18:0), %	12.36	11.80	11.75	12.59	9.67	9.75	1.17	0.27	0.94	0.05	0.04	0.90
Oleic acid (C18:1 cis-9), %	45.08	44.11	41.55	40.08	41.54	39.75	1.58	0.01	0.02	0.02	0.91	0.28
Vaccenic acid (C18:1n-7), %	0.26	0.24	0.20	0.19	0.20	0.19	0.03	0.03	0.06	0.06	0.95	0.57
Linoleic acid (C18:2n-6), %	8.41	10.27	13.54	14.42	16.96	19.30	0.64	0.001	0.001	0.001	0.001	0.003
α-Linoleic acid (C18:3n-3), %	0.43	0.53	0.58	0.67	0.71	0.77	0.03	0.001	0.001	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.25	0.23	0.23	0.32	0.25	0.22	0.02	0.40	0.12	0.89	0.09	0.39
Gadoleic acid (C20:1), %	0.81	0.79	0.73	0.84	0.78	0.76	0.06	0.59	0.76	0.54	0.76	0.66
Eicosadienoic acid (C20:2), %	0.38	0.44	0.51	0.62	0.68	0.75	0.04	0.001	0.001	0.001	0.001	0.01
Arachidonic acid (C20:4n-6), %	0.18	0.22	0.23	0.24	0.27	0.31	0.01	0.001	0.03	0.001	0.001	0.01
Other fatty acids, %	1.40	1.37	1.43	1.71	1.78	1.84	0.12	0.01	0.13	0.001	0.06	0.32
Iodine value, g/100g[8]	58.48	61.11	64.32	64.55	70.72	73.14	1.65	0.001	0.01	0.001	0.001	0.20

[1] Paylean; Elanco Animal Health (Greenfield, IN).
[2] Values represent 36 barrows (6 per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS). All values are on a DM basis. No fiber withdrawal × RAC interactions were observed.
[3] Treatments A, B vs. C, D, E, F.
[4] Treatments A, B vs. C, D.
[5] Treatments A, B vs. E, F.
[6] Treatments C, D vs. E, F.
[7] Treatments A, C, E vs. B, D, F.
[8] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 11. Effects of high fiber with or without Ractopamine HCl (RAC[1]) on fatty acid analysis of leaf fat samples[2]

Treatment:	A	B	C	D	E	F		d 0 to 49	d 49 to 73			
d 0 to 49:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber						
Item / RAC:	-	+	-	+	-	+	SEM	Corn-soy vs. high fiber[3]	Corn-soy vs. high-fiber withdrawal[4]	Corn-soy vs. high fiber[5]	High-fiber withdrawal vs. high fiber[6]	Paylean vs. no paylean[7]
Myristic acid (C14:0), %	1.45	1.41	1.60	1.45	1.39	1.45	0.07	0.45	0.14	0.85	0.11	0.43
Palmitic acid (C16:0), %	27.96	27.83	27.96	26.70	25.25	24.62	0.51	0.001	0.23	0.001	0.001	0.09
Palmitoleic acid (C16:1), %	2.32	2.25	2.12	2.07	2.00	1.90	0.13	0.02	0.13	0.01	0.24	0.48
Stearic acid (C18:0), %	18.01	18.18	17.37	16.90	15.72	14.29	0.69	0.001	0.13	0.001	0.003	0.27
Oleic acid (C18:1 cis-9), %	38.77	38.66	34.95	36.41	33.51	33.59	1.00	0.001	0.003	0.001	0.03	0.52
Vaccenic acid (C18:1n-7), %	0.18	0.17	0.16	0.18	0.16	0.15	0.01	0.31	0.74	0.17	0.28	0.86
Linoleic acid (C18:2n-6), %	8.46	8.53	12.57	12.83	18.02	19.80	0.79	0.001	0.001	0.001	0.001	0.24
α-Linoleic acid (C18:3n-3), %	0.35	0.40	0.49	0.48	0.64	0.73	0.03	0.001	0.002	0.001	0.001	0.11
Arachidic acid (C20:0), %	0.26	0.29	0.27	0.28	0.35	0.26	0.04	0.68	0.93	0.44	0.39	0.50
Gadoleic acid (C20:1), %	0.67	0.69	0.63	0.72	0.60	0.64	0.05	0.42	0.89	0.22	0.28	0.24
Eicosadienoic acid (C20:2), %	0.37	0.36	0.42	0.50	0.54	0.65	0.02	0.001	0.001	0.001	0.001	0.002
Arachidonic acid (C20:4n-6), %	0.11	0.15	0.16	0.14	0.24	0.27	0.02	0.001	0.30	0.001	0.001	0.41
Other fatty acids, %	1.09	1.07	1.30	1.34	1.59	1.66	0.13	0.001	0.06	0.001	0.02	0.75
Iodine value, g/100g[8]	51.80	51.89	55.74	57.48	64.20	67.52	1.44	0.001	0.001	0.001	0.001	0.12

[1] Paylean; Elanco Animal Health (Greenfield, IN).
[2] Values represent 36 barrows (6 per treatment) selected for harvest at the Kansas State University Meats Lab (Manhattan, KS). All values are on a DM basis. No fiber withdrawal × RAC interactions were observed.
[3] Treatments A, B vs. C, D, E, F.
[4] Treatments A, B vs. C, D.
[5] Treatments A, B vs. E, F.
[6] Treatments C, D vs. E, F.
[7] Treatments A, C, E vs. B, D, F.
[8] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Effects of Diet Form and Fiber Withdrawal Before Marketing on Growth Performance of Growing-Finishing Pigs[1,2]

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Summary

A total of 288 pigs (PIC 327 × 1050, initially 109.3 lb BW) were used in an 81-d trial to determine the effects of diet form and fiber (from dried distillers grains with solubles [DDGS] and wheat middlings) withdrawal before harvest on growth performance of growing-finishing pigs. Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and dietary fiber feeding regimen. The 2 diet forms were meal or pellet. The 3 fiber feeding regimens were (1) low dietary fiber (corn-soybean meal–based diets) from d 0 to 81, (2) high dietary fiber (30% DDGS and 19% wheat midds) from d 0 to 64 followed by low fiber from d 64 to 81 (fiber withdrawal), and (3) high dietary fiber from d 0 to 81.

No interactions ($P > 0.13$) were observed for growth performance between diet form and fiber withdrawal regimens. From d 0 to 64, there were no differences ($P > 0.27$) in ADG between pigs fed different diet forms. Pigs fed meal diets had increased ($P < 0.02$) ADFI and poorer ($P < 0.001$) F/G compared with pigs fed pelleted diets. Pigs fed pelleted diets tended ($P < 0.08$) to have increased final BW and HCW compared with pigs fed meal diets, but no difference ($P > 0.28$) was detected in carcass yield. From d 0 to 64, fiber level did not influence ADG ($P > 0.64$); however, pigs fed low-fiber diets had decreased ($P < 0.01$) ADFI and improved ($P < 0.001$) F/G compared with pigs fed high-fiber diets. From d 64 to 81, pigs fed pelleted diets had increased $P < 0.005$) ADG and tended to have increased ($P < 0.10$) ADFI and better F/G ($P < 0.06$) than pigs fed meal diets. Pigs on the fiber withdrawal regimen had increased ($P < 0.03$) ADG compared with pigs kept on high-fiber diets; pigs previously fed the low-fiber diet were intermediate. Withdrawal of the high-fiber diet resulted in an increase ($P < 0.001$) in ADFI compared with pigs fed low-fiber or high-fiber diets throughout. Pigs fed low-fiber diets throughout the trial had improved ($P < 0.02$) F/G compared with pigs fed high-fiber diets throughout, and pigs on the withdrawal regimen were intermediate.

Overall (d 0 to 81), pigs fed pelleted diets had increased ($P < 0.03$) ADG and improved ($P < 0.001$) F/G compared with pigs fed meal, with no difference ($P > 0.12$) in ADFI. Fiber regimen did not influence ($P > 0.35$) ADG for the overall trial; however, pigs fed low fiber throughout the trial had decreased ($P < 0.001$) ADFI and improved ($P < 0.001$) F/G compared with pigs fed the withdrawal regimen or pigs fed high fiber

[1] Appreciation is expressed to Hubbard Feeds Inc. (Beloit, KS) for providing feed manufacturing services and to Clint Scheck for technical assistance.

[2] Appreciation is expressed to Farmland Foods (Crete, NE) for collecting carcass weights and fat samples and to Cory Rains and Roger Johnson for technical assistance.

[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

throughout. Fiber regimen did not affect ($P > 0.11$) final BW or HCW, but the fiber withdrawal regimen restored carcass yield to the low-fiber pigs, both of which were greater than those fed the high-fiber regimen ($P < 0.001$). For carcass fat quality, pigs fed pelleted diets had increased ($P < 0.001$) belly fat iodine value (IV) compared with pigs fed meal diets. Compared with pigs fed high fiber throughout the trial, pigs fed the low-fiber regimen had decreased ($P < 0.001$) IV, with those fed the withdrawal regimen intermediate. Compared with pigs fed low-fiber diets throughout, feeding high-fiber diets increased ADFI and resulted in poorer F/G, regardless of withdrawal. Withdrawing fiber allowed pigs to recover fully from losses in carcass yield, but only an intermediate improvement in belly fat IV was observed. Pelleting the diets improved ADG and F/G, but worsened belly fat IV, regardless of diet formulation; however, pelleting increased belly fat IV to a greater extent with the high-fiber diet containing DDGS and wheat midds than with the low fiber, corn-soybean meal diet.

Key words: DDGS, diet form, pellet, finishing pig, wheat middlings

Introduction

The inclusion of by-products as alternatives to corn and soybean meal in swine diets has greatly increased in recent years. Two common by-products that have been evaluated are DDGS and wheat midds. These are high-fiber ingredients that may provide a decrease in feed costs, but past research has demonstrated that high inclusion rates can also negatively affect growth performance, carcass yield, and carcass fat quality. One successful strategy to reduce these negative effects is withdrawing DDGS and wheat midds before harvest; however, the majority of these experiments have been conducted using meal diets. With increasing cost of cereal grains, more emphasis is being placed on improving feed efficiency by pelleting swine diets, but little information is available on the relationship between diet form and fiber feeding strategy. Therefore, the objective of this trial was to determine the effects of diet form and fiber withdrawal on growth performance, carcass yield, and carcass fat quality of growing-finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (8 ft × 10 ft). The pens had adjustable gates facing the alleyway and allowed 10 ft^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A total of 288 pigs (PIC 327 × 1050, initially 109.3 lb BW) were used in an 81-d trial. Pens were randomly allotted to 1 of 6 experimental treatments by initial BW with 6 pens per treatment with 8 pigs per pen (4 barrows and 4 gilts per pen). Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and dietary fiber feeding regimen. The 2 diet forms used were meal or pellet. The 3 fiber feeding regimens were (1) low dietary fiber (corn-soybean meal) from d 0 to 81, (2) high dietary fiber (30% DDGS and 19% wheat midds) from d 0 to 64 followed by low fiber from d 64 to 81 (fiber withdrawal), and (3) high dietary fiber from d 0 to 81 (Table 1). Diets were fed in 4 phases from d 0 to 14, d 15 to 40, d 40 to 64, and d 64 to 81, respectively. Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, and F/G. Diets were prepared and pelleted at Hubbard Feeds in Beloit, KS. Pelleted feed was processed with a Sprout Waldron Pellet Mill, model Ace 501, equipped with a 11/64-in. diameter die. Diets were delivered in bulk and fed through bulk bins. Feed samples were taken at the feeder during each phase. Pellet durability index (PDI) was determined using the standard tumbling-box technique and modified PDI was done by adding 5 hexagonal nuts prior to tumbling. Percentage fines were also determined for all pelleted diets.

On d 81, all pigs were weighed individually, then transported to Farmland Foods (Crete, NE). Pigs were individually tattooed in sequential order by pen to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration and were used to calculate percentage yield by dividing HCW at the plant by live weight at the farm before transport. Fat samples were collected from the ventral side of the belly along the navel edge of each pig and analyzed for fatty acid profiles and calculation of IV.

Experimental data were analyzed using analysis of variance as a 2 × 3 factorial with 2 diet forms and 3 fiber regimens and their interaction as fixed effects using the PROC MIXED procedure of SAS. Differences between treatments were determined using the PDIFF statement in SAS. Pen was the experimental unit for all data analysis. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

Pellet quality measurements. Pellet durability index was excellent, with standard PDI greater than 90% during all phases for pelleted diets (Table 2). Percentage fines were low for all diets and phases at less than 10% fines.

Growth performance and carcass weight. No diet form × fiber regimen interactions ($P > 0.13$) were observed for growth performance during any of the dietary phases or for the overall trial (Table 3).

From d 0 to 64, ADG did not differ ($P > 0.27$) among pigs fed different diet forms (Table 4). Pigs fed meal diets had increased ($P < 0.02$) ADFI and poorer ($P < 0.001$) F/G than pigs fed pelleted diets. Fiber level did not influence ADG ($P > 0.64$); however, pigs fed low-fiber diets from d 0 to 64 had decreased ($P < 0.01$) ADFI and improved ($P < 0.001$) F/G compared with pigs fed high-fiber diets during this period (Table 5).

From d 64 to 81, pigs fed pelleted diets had increased ($P < 0.005$) ADG and tended to have increased ($P < 0.10$) ADFI compared with pigs fed meal diets. Feeding pelleted diets also tended to improve ($P < 0.06$) F/G. Pigs previously fed high-fiber diets, then switched to low-fiber diets during this phase, had increased ($P < 0.03$) ADG compared with pigs maintained on the high-fiber diets. Pigs fed the low-fiber diets throughout the trial had intermediate ADG. Pigs previously fed high-fiber diets and switched to the low-fiber diet had increased ($P < 0.001$) ADFI compared with pigs fed low-fiber or high-fiber diets throughout. Pigs fed low-fiber diets throughout the trial had improved ($P < 0.02$) F/G compared with pigs fed high-fiber diets throughout, and pigs that were withdrawn from the high-fiber diet were intermediate.

Overall (d 0 to 81), pigs fed pelleted diets had increased ($P < 0.03$) ADG and improved ($P < 0.001$) F/G compared with pigs fed meal diets. There was no difference ($P > 0.12$) in ADFI between pigs fed the different diet forms. Pigs fed pelleted diets tended ($P < 0.08$) to have increased final BW and HCW compared with pigs fed meal diets, but carcass yield did not differ ($P > 0.28$). Fiber regimen did not influence ($P > 0.35$) ADG for the overall trial, but pigs fed low fiber throughout the trial had increased ($P < 0.001$) ADFI and improved ($P < 0.001$) F/G compared with pigs on the high-fiber withdrawal or pigs fed high fiber throughout. Fiber regimen did not affect ($P > 0.11$) final BW or HCW, but pigs fed high fiber throughout the trial had decreased ($P < 0.001$) carcass yield compared with pigs fed the other fiber regimens. These results are similar to those of Asmus et al. (2011[4]), where removing high-fiber ingredients (DDGS and wheat midds) from the diet before harvest improved carcass yield and returned carcass weights to values similar to control pigs fed corn-soybean meal–based diets throughout the trial.

Belly fatty acid composition. Interactive effects between diet form and fiber regimen were detected ($P < 0.05$) for palmitic (C16:0) and linoleic (C18:2n6c) acid concentrations (Table 6). These were caused by a greater magnitude of change in fatty acid concentrations between pellet and meal diets when the diet contained high fiber than when the diet was low in fiber. Pelleting diets appeared to worsen the impact on belly fat IV of the high oil content in DDGS. Palmitic and total C18:2 fatty acids account for the greatest portions of SFA and PUFA, respectively. As a result, interactions were also detected ($P < 0.01$) for total SFA, total PUFA, UFA:SFA, PUFA:SFA ratios, and belly fat IV.

Pelleting diets reduced ($P < 0.001$) myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), oleic (C18:1n9c), and vaccenic (C18:1n7) fatty acids; however, pelleting increased ($P < 0.001$) linoleic (C18:2n6c), α-linolenic (C18:3n3), eicosadienoic (C20:2), and total C18:2 fatty acids (Table 7). As a result, total PUFA and belly fat IV increased ($P < 0.001$), whereas total SFA, MUFA, and all other fatty acids decreased ($P < 0.001$) when pigs were fed pelleted diets. There were no differences ($P > 0.15$) in stearic (C18:0), arachidic (20:0), eicosenoic (20:1), or arachidonic (C20:4n6) fatty acids between pigs fed the different diet forms. The greater belly fat IV pigs fed pelleted diets was unexpected, particularly because faster-growing pigs will have a lower IV than slower-growing pigs. Lo Fiego et al. (2005[5]) reported that pigs with heavier BW and HCW had decreased PUFA and IV compared with lighter pigs. To our knowledge, the current trial is the first report of fatty acid change due to diet form. Additional research should be conducted to further investigate the effects of pelleting on fatty acid profile of finishing pigs.

[4] Asmus et al., Swine Day 2011, Report of Progress 1056, pp. 202–215.

[5] Lo Fiego D. P., Santero P., Macchioni P., De Leonibus E. 2005. Influence of genetic type, live weight at harvest and carcass fatness on fatty acid composition of subcutaneous adipose tissue of raw ham in the heavy pig. Meat Sci. 69:107–114.

Compared with pigs fed high fiber throughout the trial, pigs fed low fiber throughout the trial had increased ($P < 0.001$) C16:0, C18:0, C18:1n9c, C18:1n7, total SFA, and total MUFA concentrations, with those fed the withdrawal regimen intermediate ($P < 0.001$) (Table 8). Pigs fed the low-fiber diet had decreased ($P < 0.001$) C18:2n6C, C18:3n3, C20:2, C20:4n6, total C18:2, PUFA, and belly fat IV than those fed high fiber, with those on the withdrawal regiment intermediate ($P < 0.001$). These changes in fatty acid profile, specifically decreases in total PUFA and IV, suggest that withdrawing fiber (from DDGS and wheat midds) from the diet before harvest allowed for improved fat quality compared with feeding high fiber; however, this approach did not return fatty acid concentrations to pigs fed low fiber throughout. Notably, withdrawing fiber sources also reduced the intake of PUFA provided in the diet; thus, the decrease in belly IV value is most likely related to PUFA intake rather than a direct effect of the fiber on PUFA profile.

Regardless of withdrawal, pigs fed higher-fiber diets during any period of the experiment had decreased ($P < 0.001$) C14:0 and C16:1 concentrations and increased ($P < 0.001$) C17:0 concentrations compared with pigs fed low fiber for the entire trial. Feeding high-fiber diets throughout the experiment decreased ($P < 0.001$) C20:0 concentrations compared with the other two regimens, indicating that withdrawing fiber allowed C20:0 concentrations to return to a level similar to that of pigs fed low fiber throughout. No differences ($P > 0.36$) were detected in C20:1 among pigs fed the different fiber regimens. The response to belly fat IV in the current trial is in agreement with past research[4], where withdrawing fiber from the diet allowed for intermediate improvements in carcass fat IV. As expected, Asmus et al. (2011[6]) found that the DDGS component of the high-fiber diet caused the greatest increase in IV, with a smaller increase due to the wheat midds. The high oil content in DDGS has consistently been shown to increase IV of fat stores. Withdrawing high-oil ingredients such as DDGS before harvest appears to be an effective strategy to lowering carcasss fat IV in finishing pigs.

In summary, pelleting the diets improved ADG and F/G, but for unknown reasons increased the amount of unsaturated fatty acids in the belly, resulting in higher IV than pigs fed meal diets. This increase in belly fat IV was greater when the high-fiber diets were fed than when the corn-soybean meal diet was fed, but due to the higher level of unsaturated fatty acids in the high-fiber ingredients used. Compared with pigs fed low-fiber diets throughout, feeding high-fiber diets increased ADFI and resulted in poorer F/G, regardless of withdrawal. Consistent with previous research, high-fiber withdrawal allowed pigs to recover fully the losses in carcass yield associated with feeding high fiber levels, but only an intermediate improvement in belly fat IV was observed.

[6] Asmus et al., Swine Day 2011, Report of Progress 1056, pp. 216–226.

Table 1. Diet composition (as-fed basis)

	Phase 1[1]		Phase 2[2]		Phase 3[3]		Phase 4[4]	
Item Fiber level:[5]	Low	High	Low	High	Low	High	Low	High
Ingredient, %								
Corn	73.71	34.88	78.93	39.99	82.65	43.56	84.97	45.79
Soybean meal (46.5% CP)	23.80	13.74	18.84	8.71	15.32	5.20	13.15	3.04
Dried distillers grains with solubles	---	30.00	---	30.00	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00	---	19.00	---	19.00
Monocalcium phosphate (21% P)	0.45	---	0.35	---	0.25	---	0.20	---
Limestone	1.05	1.30	1.00	1.28	0.98	1.29	0.93	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
Trace mineral premix	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
L-lysine HCl	0.170	0.310	0.150	0.293	0.135	0.278	0.128	0.270
DL-methionine	0.020	---	---	---	---	---	---	---
L-threonine	0.025	---	0.010	---	---	---	---	---
Phytase[6]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lysine	0.93	0.93	0.79	0.79	0.69	0.69	0.63	0.63
Isoleucine:lysine	69	72	70	74	72	76	73	78
Methionine:lysine	30	34	30	37	32	40	33	43
Met & Cys:lysine	59	70	62	77	66	83	69	88
Threonine:lysine	63	66	63	69	64	72	66	74
Tryptophan:lysine	19	19	19	19	19	19	19	19
Valine:lysine	78	88	81	94	85	99	87	103
Total lysine, %	1.04	1.09	0.89	0.94	0.78	0.83	0.72	0.77
ME, kcal/lb	1,513	1,484	1,516	1,486	1,520	1,487	1,522	1,488
CP, %	17.5	20.8	15.6	18.9	14.3	17.6	13.5	16.7
Ca, %	0.59	0.58	0.53	0.56	0.49	0.55	0.46	0.54
P, %	0.47	0.58	0.42	0.56	0.39	0.55	0.37	0.54
Available P, %	0.27	0.39	0.25	0.38	0.22	0.38	0.21	0.37

[1] Phase 1 diets were fed from d 0 to 15.
[2] Phase 2 diets were fed from d 15 to 40.
[3] Phase 3 diets were fed from d 40 to 64.
[4] Phase 4 diets were fed from d 64 to 81.
[5] Each diet was fed in either meal or pellet form.
[6] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 354 phytase units (FTU)/lb, with a release of 0.11% available P.

Table 2. Analysis of pellet quality

	Fiber level	
Item	Low[1]	High[2]
Standard pellet durability index, %[3]		
Phase 1	91.0	92.7
Phase 2	90.1	96.2
Phase 3	92.9	95.9
Phase 4	94.9	91.4
Modified pellet durability index[4]		
Phase 1	87.9	89.4
Phase 2	86.3	92.7
Phase 3	89.5	93.8
Phase 4	92.4	88.8
Fines, %		
Phase 1	7.6	7.3
Phase 2	9.0	7.4
Phase 3	8.0	8.4
Phase 4	7.9	8.1

[1] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings.
[2] Refers to diet with 30% DDGS and 19% wheat middlings.
[3] Pellet durability index was determined using the standard tumbling-box technique.
[4] Procedure was altered by adding 5 hexagonal nuts prior to tumbling.

Table 3. Effects of fiber and diet form on finishing pig growth performance[1]

	Diet form							Probability, $P<$		
Fiber level:	Meal			Pellet						
d 0 to 64:	Low[2]	High[3]	High	Low	High	High		Diet form	Meal vs.	Fiber
d 64 to 81:	Low	Low	High	Low	Low	High	SEM	× fiber	pellet	regimen
d 0 to 64										
ADG, lb	2.10	2.14	2.11	2.15	2.16	2.18	0.047	0.92	0.27	0.64
ADFI, lb	5.45	5.81	5.85	5.31	5.49	5.56	0.120	0.76	0.02	0.01
F/G	2.60	2.72	2.76	2.47	2.55	2.56	0.035	0.52	0.001	0.001
d 64 to 81										
ADG, lb	2.05	2.13	1.93	2.24	2.26	2.13	0.071	0.89	0.005	0.03
ADFI, lb	6.45	7.20	7.09	6.95	7.46	6.96	0.153	0.13	0.10	0.001
F/G	3.17	3.38	3.72	3.11	3.30	3.28	0.121	0.25	0.06	0.02
d 0 to 81										
ADG, lb	2.08	2.13	2.09	2.17	2.18	2.17	0.038	0.83	0.03	0.35
ADFI, lb	5.65	6.10	6.11	5.64	5.89	5.85	0.119	0.57	0.12	0.001
F/G	2.71	2.86	2.94	2.61	2.71	2.70	0.037	0.19	0.001	0.001
BW, lb										
d 0	109.5	108.8	109.8	109.2	110.1	108.6	2.93	0.91	0.97	0.93
d 64	244.6	245.5	245.1	248.1	248.5	247.9	4.12	0.99	0.37	0.88
d 81	279.6	281.7	278.0	287.4	287.0	284.3	4.16	0.94	0.07	0.44
Carcass yield, %	75.1	74.7	74.1	75.0	74.8	73.4	0.24	0.88	0.28	0.001
HCW, lb	210.2	210.4	206.1	215.7	214.9	208.7	3.55	0.13	0.08	0.11

[1] A total of 288 pigs (PIC 327 × 1050, initially 109.3 lb BW) were used in an 81-d trial to determine the effects of diet form and lowering fiber levels prior to marketing on growth performance of growing-finishing pigs.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings.

[3] Refers to diet with 30% DDGS and 19% wheat middlings.

Table 4. Main effects of diet form on finishing pig growth performance

	Diet form			
	Meal	Pellet	SEM	Probability, *P*<
d 0 to 64				
ADG, lb	2.12	2.16	0.027	0.27
ADFI, lb	5.70	5.45	0.069	0.02
F/G	2.69	2.53	0.020	0.001
d 64 to 81				
ADG, lb	2.04	2.21	0.041	0.005
ADFI, lb	6.91	7.12	0.088	0.10
F/G	3.43	3.23	0.070	0.06
d 0 to 81				
ADG, lb	2.10	2.17	0.022	0.03
ADFI, lb	5.95	5.80	0.069	0.12
F/G	2.83	2.67	0.021	0.001
BW, lb				
d 0	109.4	109.3	1.69	0.97
d 64	245.1	248.1	2.38	0.37
d 81	279.7	286.2	2.40	0.07
Carcass yield, %	74.6	74.4	0.14	0.28
HCW, lb	208.9	213.1	1.70	0.08

[1] A total of 288 pigs (PIC 327 × 1050, initially 109.3 lb BW) were used in an 81-d trial to determine the effects of diet form and lowering fiber levels prior to marketing on growth performance of growing-finishing pigs.

Table 5. Main effects of fiber on finishing pig growth performance

	Fiber level				
d 0 to 64:	Low	High	High		
d 64 to 81:	Low	Low	High	SEM	Probability, *P*<
d 0 to 64					
ADG, lb	2.13	2.15	2.14	0.033	0.64
ADFI, lb	5.38[a]	5.65[b]	5.70[b]	0.085	0.01
F/G	2.53[a]	2.63[b]	2.66[b]	0.025	0.001
d 64 to 81					
ADG, lb	2.14[ab]	2.20[a]	2.03[b]	0.050	0.03
ADFI, lb	6.70[b]	7.33[a]	7.02[b]	0.108	0.001
F/G	3.14[a]	3.34[ab]	3.50[b]	0.085	0.02
d 0 to 81					
ADG, lb	2.13	2.16	2.12	0.027	0.35
ADFI, lb	5.65[a]	6.00[b]	5.98[b]	0.084	0.001
F/G	2.66[a]	2.78[b]	2.82[b]	0.026	0.001
BW, lb					
d 0	109.4	109.5	109.2	2.07	0.93
d 64	246.4	247.0	246.5	2.91	0.88
d 81	283.5	284.3	281.1	2.94	0.65
Carcass yield, %	75.1[a]	74.8[a]	73.7[b]	0.17	0.001
HCW, lb	213.0	212.6	207.4	2.06	0.11

[a,b] Means with different superscripts differ significantly, $P < 0.05$.

[1] A total of 288 pigs (PIC 327 × 1050, initially 109.3 lb BW) were used in an 81-d trial to determine the effects of diet form and lowering fiber levels prior to marketing on growth performance of growing-finishing pigs.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings.

[3] Refers to diet with 30% DDGS and 19% wheat middlings.

Table 6. Effects of fiber and diet form on finishing pig belly fat fatty acid profile[1]

	Diet form									
Fiber level:	Meal			Pellet				Probability, *P*<		
d 0 to 64:	Low[2]	High[3]	High	Low	High	High		Diet form	Meal vs.	Fiber
Item d 64 to 81:	Low	Low	High	Low	Low	High	SEM	× fiber	pellet	regimen
Myristic acid (C14:0), %	1.47	1.39	1.36	1.44	1.31	1.29	0.018	0.59	0.001	0.001
Palmitic acid (C16:0), %	23.91	22.49	21.87	23.68	21.67	21.04	0.130	0.05	0.001	0.001
Palmitoleic acid (C16:1), %	3.30	3.06	2.96	3.03	2.66	2.62	0.061	0.81	0.001	0.001
Margaric acid (C17:0), %	0.35	0.39	0.43	0.33	0.36	0.38	0.014	0.45	0.002	0.001
Stearic acid (C18:0), %	10.61	9.44	8.94	10.79	9.21	8.64	0.114	0.07	0.19	0.001
Oleic acid (C18:1n9c), %	39.45	37.84	36.73	38.71	36.59	35.73	0.214	0.65	0.001	0.001
Vaccenic acid (C18:1n7), %	4.27	3.95	3.76	4.02	3.57	3.47	0.051	0.87	0.001	0.001
Linoleic acid (C18:2n6c), %	12.89	17.22	19.57	14.25	20.38	22.51	0.290	0.01	0.001	0.001
Total C18:2 fatty acids, %[4]	13.05	17.41	19.75	14.38	20.52	22.64	0.290	0.01	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.58	0.68	0.74	0.63	0.80	0.84	0.014	0.16	0.001	0.001
Arachidic acid (C20:0), %	0.22	0.22	0.21	0.23	0.22	0.21	0.004	0.53	0.57	0.001
Eicosenoic acid (C20:1), %	0.65	0.67	0.66	0.67	0.66	0.63	0.015	0.33	0.58	0.36
Eicosadienoic acid (C20:2), %	0.59	0.78	0.85	0.65	0.90	0.95	0.012	0.15	0.001	0.001
Arachidonic acid (C20:4n6), %	0.25	0.29	0.30	0.24	0.28	0.29	0.006	0.84	0.15	0.001
Other fatty acids, %	1.30	1.42	1.46	1.22	1.26	1.29	0.018	0.05	0.001	0.001
Total SFA, %[5]	36.94	34.29	33.18	36.82	33.12	31.90	0.208	0.01	0.001	0.001
Total MUFA, %[6]	48.25	46.16	44.76	46.95	43.99	42.96	0.286	0.56	0.001	0.001
Total PUFA, %[7]	14.80	19.55	22.06	16.23	22.89	25.15	0.318	0.02	0.001	0.001
UFA:SFA, ratio[8]	1.71	1.92	2.02	1.72	2.03	2.14	0.018	0.01	0.001	0.001
PUFA:SFA, ratio[9]	0.40	0.57	0.67	0.44	0.69	0.79	0.012	0.001	0.001	0.001
Iodine value[10]	65.7	71.7	74.7	67.0	75.5	78.4	0.378	0.003	0.001	0.001

[1] All items calculated as a percentage of the total fatty acid content.
[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings.
[3] Refers to diet with 30% DDGS and 19% wheat middlings.
[4] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[5] Total SFA = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[6] Total MFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[7] Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].
[8] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.
[9] PUFA:SFA ratio = total PUFA / total SFA.
[10] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.

Table 7. Main effects of diet form on finishing pig fatty acid profile[1]

	Diet form			
Item	Meal	Pellet	SEM	Probability, *P*<
Myristic acid (C14:0), %	1.39	1.33	0.016	0.001
Palmitic acid (C16:0), %	22.64	22.01	0.112	0.001
Palmitoleic acid (C16:1), %	3.03	2.69	0.054	0.001
Margaric acid (C17:0), %	0.39	0.36	0.009	0.001
Stearic acid (C18:0), %	9.66	9.54	0.065	0.19
Oleic acid (C18:1n9c), %	37.84	36.84	0.180	0.001
Vaccenic acid (C18:1n7), %	3.88	3.57	0.047	0.001
Linoleic acid (C18:2n6c), %	17.09	19.60	0.268	0.001
Total C18:2 fatty acids, %[2]	17.26	19.73	0.267	0.001
α-Linolenic acid (C18:3n3), %	0.70	0.79	0.013	0.001
Arachidic acid (C20:0), %	0.22	0.22	0.002	0.57
Eicosenoic acid (C20:1), %	0.66	0.65	0.008	0.58
Eicosadienoic acid (C20:2), %	0.77	0.86	0.012	0.001
Arachidonic acid (C20:4n6), %	0.28	0.27	0.005	0.15
Other fatty acids, %	1.39	1.25	0.010	0.001
Total SFA, %[3]	34.72	33.85	0.160	0.001
Total MUFA, %[4]	46.00	44.24	0.258	0.001
Total PUFA, %[5]	19.42	22.05	0.294	0.001
UFA:SFA, ratio[6]	1.90	1.97	0.014	0.001
PUFA:SFA, ratio[7]	0.57	0.67	0.011	0.001
Iodine value[8]	71.3	74.3	0.346	0.001

[1] All items calculated as a percentage of the total fatty acid content.
[2] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].
[3] Total SFA = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].
[4] Total MUFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].
[5] Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].
[6] UFA:SFA ratio = [total MUFA + total PUFA] / total SFA.
[7] PUFA:SFA ratio = total PUFA / total SFA.
[8] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.

Table 8. Main effects of diet regimen on finishing pig fatty acid profile[1]

	Fiber level				
d 0 to 64:	Low[2]	High[3]	High		
Item d 64 to 81:	Low	Low	High	SEM	Probability, *P*<
Myristic acid (C14:0), %	1.44[a]	1.33[b]	1.31[b]	0.018	0.001
Palmitic acid (C16:0), %	23.67[a]	21.95[b]	21.36[c]	0.127	0.001
Palmitoleic acid (C16:1), %	3.09[a]	2.78[b]	2.73[b]	0.062	0.001
Margaric acid (C17:0), %	0.34[a]	0.38[b]	0.40[b]	0.010	0.001
Stearic acid (C18:0), %	10.70[a]	9.32[b]	8.79[c]	0.078	0.001
Oleic acid (C18:1n9c), %	38.91[a]	37.03[b]	36.09[c]	0.206	0.001
Vaccenic acid (C18:1n7), %	4.03[a]	3.64[b]	3.52[c]	0.054	0.001
Linoleic acid (C18:2n6c), %	14.14[a]	19.40[b]	21.50[c]	0.303	0.001
Total C18:2 fatty acids, %[4]	14.28[a]	19.56[b]	21.65[c]	0.303	0.001
α-Linolenic acid (C18:3n3), %	0.64[a]	0.77[b]	0.82[c]	0.014	0.001
Arachidic acid (C20:0), %	0.22[a]	0.22[a]	0.21[b]	0.003	0.001
Eicosenoic acid (C20:1), %	0.66	0.66	0.64	0.010	0.36
Eicosadienoic acid (C20:2), %	0.65[a]	0.87[b]	0.93[c]	0.013	0.001
Arachidonic acid (C20:4n6), %	0.25[a]	0.29[b]	0.30[c]	0.006	0.001
Other fatty acids, %	1.26[a]	1.34[b]	1.37[b]	0.013	0.001
Total SFA, %[5]	36.79[a]	33.60[b]	32.46[c]	0.185	0.001
Total MUFA, %[6]	47.19[a]	44.64[b]	43.53[c]	0.293	0.001
Total PUFA, %[7]	16.17[a]	21.91[b]	24.13[c]	0.333	0.001
UFA:SFA, ratio[8]	1.73[a]	1.99[b]	2.09[c]	0.017	0.001
PUFA:SFA, ratio[9]	0.45[a]	0.66[b]	0.75[c]	0.012	0.001
Iodine value (IV)[10]	67.0[a]	74.3[b]	77.1[c]	0.393	0.001

[1] All items calculated as a percentage of the total fatty acid content.

[2] Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings.

[3] Refers to diet with 30% DDGS and 19% wheat middlings.

[4] Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[5] Total SFA = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[6] Total MUFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[7] Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].

[8] UFA:SFA ratio = [total MUFA + total PUFA] / Total SFA.

[9] PUFA:SFA ratio = total PUFA / total SFA.

[10] Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.

Effect of Diet Form and Feeder Adjustment on Growth Performance of Nursery Pigs[1,2]

J. E. Nemechek, M. D. Tokach, E. Fruge[3], E. Hansen[3], S. S. Dritz[4], R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen

Summary

Two experiments were conducted to determine the effect of feeder adjustment and diet form on growth performance of nursery pigs. In Exp. 1, a total of 210 nursery pigs (PIC 1050 × 327, initially 26.2 lb BW) were used in a 21-d trial. In Exp. 2, a total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars, initially 31.1 lb BW) were used in a 28-d trial. Treatments in both experiments were arranged as 2 × 3 factorials with main effects of feeder adjustment and diet form. The 2 feeder adjustments consisted of a narrow feeder adjustment (minimum gap opening of 0.50 in.) and a wide adjustment (minimum gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75 or 1.25 in, respectively. The 3 diet forms were meal, poor-quality pellets (70% pellets and 30% fines), and screened pellets with minimal fines. Pigs were weighed weekly to calculate ADG, ADFI, and F/G.

In Exp. 1 (d 0 to 21), no differences ($P > 0.13$) were observed in ADG, ADFI, or F/G among pigs fed from feeders with different adjustment settings. Surprisingly, pigs fed the meal diet had increased ($P < 0.001$) ADG and ADFI compared with pigs fed the 70% pellets + 30% fines or screened pellets. Pigs fed screen pellets had improved ($P < 0.004$) F/G compared with pigs fed meal or 70% pellets + 30% fines. In Exp. 2 (d 0 to 28), pigs fed from the wide feeder adjustment had increased ($P < 0.03$) ADG and ADFI. There was no difference ($P > 0.70$) in F/G among pigs fed from the different feeder adjustments. Pigs fed screened pellets or 70% pellets + 30% fines had increased ($P < 0.03$) ADG compared with pigs fed the meal diet. No difference ($P > 0.25$) in ADFI was observed among pigs fed different diet forms. Similar to Exp. 1, pigs fed screened pellets had improved ($P < 0.01$) F/G compared with pigs fed meal or 70% pellets + 30% fines. The combined results suggest that feeding nursery pigs from a wide feeder gap may provide benefits in ADG and ADFI with no negative effects on F/G. An improvement in F/G was observed only in pigs fed the screened pellets; therefore, the percentage of fines in the diets must be minimized to obtain maximum benefits to feed efficiency from pelleting.

Key words: diet form, feeder adjustment, pellet, nursery pig

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[1] Appreciation is expressed to Hubbard Feeds Inc., Mankato, MN, for providing feed and manufacturing services.
[2] Appreciation is expressed to New Fashion Pork for use of pigs and facilities.
[3] Hubbard Feeds Inc. (Mankato, MN).
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Introduction

Past research at Kansas State University has demonstrated that proper feeder gap adjustment plays an important role in decreasing feed wastage and improving F/G in growing-finishing pigs; however, the majority of the available research on feeder adjustment has been conducted using meal diets. The experiments also found that tight feeder adjustment reduced growth rate, particularly for pigs housed in field conditions. In addition, pelleting diets has been shown to improve F/G, but the magnitude of improvement is influenced by pellet quality and the percentage of fines. With increases in the cost of cereal grains, the impact of improving feed efficiency is becoming a more critical area of interest. More research is required to optimize feed efficiency and determine the relationship between feeder gap adjustment and diet form; thus, the objective of these experiments was to determine the effects of feeder adjustment and diet form on growth performance of nursery pigs.

Procedures

The K-State Institutional Animal Care and Use Committee approved the protocol used in these experiments. Experiment 1 was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS, and Exp. 2 was conducted at a commercial nursery research facility in Iowa.

In Exp. 1, a total of 210 nursery pigs (PIC 1050 × 327, initially 26.2 lb BW) were used in a 21-d trial with 7 pigs were pen and 5 pens per treatment. All pens (4 ft × 5 ft) contained a 4-hole, dry self-feeder and a nipple waterer. In Exp. 2, a total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars, initially 31.1 lb BW) were used in a 28-d trial, with 25 pigs per pen and 7 pens per treatment.

Similar diets and procedures were used in both experiments. Pens were randomly allotted to 1 of 6 experimental treatments. Treatments were arranged in a 2 × 3 factorial with the main effects of feeder adjustment and diet form. The 2 feeder adjustment treatments consisted of a narrow feeder adjustment (minimum gap opening of 0.50 in.) and a wide adjustment (minimum gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75 or 1.25 in., respectively. The 3 diet form treatments consisted of meal, poor-quality pellets (70% pellets and 30% fines), and screened pellets with minimal fines. Diets for both experiments were corn-soybean meal–based with 20% DDGS and were formulated to contain identical ingredient compositions within each experiment (Table 1). All pigs were provided with ad libitum access to feed and water. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and F/G. Pictures were taken of feeder pan coverage on d 21 or 28 for Exp. 1 and 2, respectively, then scored by a panel of 5 evaluators for percentage of pan coverage.

Diets were prepared and pelleted at the K-State Grain Science Feed Mill and Hubbard Feeds in Atlantic, IA, for Exp. 1 and 2, respectively. In accordance with the capabilities of each feed mill, the desired level of fines in the poor-quality pellets were created by 2 different methods. For Exp. 1, pellets were manufactured and screened to remove and collect fines. After the screened pelleted diet was bagged, the fines were added back to the remaining pellets. The mixture of pellets and fines was then added to the mixer, and additional fines were created in the mixer by mechanical breakdown. For Exp. 2, the pellets were passed through the roller mill, rather than the mixer, to create the additional fines.

Feed samples were taken at the feeder and pooled throughout the entire trial. At the end of the experiment, a composite feed sample for each phase was measured for percentage of fines in the pelleted diet. Fines were characterized by material that would pass through a #6 sieve (3,360 μm openings).

Experimental data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatments were arranged as a 2 × 3 factorial with 2 feeder adjustments and 3 diet forms. Differences between treatments were determined using the PDIFF statement in SAS. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

Experiment 1

The narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 42, 46, and 37%, respectively (Table 2). Representative pictures of mean pan coverage score are listed in Figures 1, 2, and 3, respectively. The wide feeder adjustment pan coverage scores averaged 92, 98, and 93% for the meal, poor-quality pellets, and screened pellets diets, respectively (Figures 4, 5, and 6, respectively). When percentage fines were measured, the poor-quality pellets contained 67% pellets and 33% fines, whereas the screened pelleted diet was 97% pellets and 3% fines (Table 3).

No interactions ($P > 0.19$) were detected between feeder gap adjustment and diet form for pig performance (Table 4). Overall (d 0 to 21), no differences ($P > 0.13$) were observed in ADG, ADFI, or F/G between pigs fed from feeders with the different adjustment settings (Table 5). Pigs fed the meal diet had increased ($P < 0.001$) ADG and ADFI compared with pigs fed the 70% pellets + 30% fines or screened pellets (Table 6). Pigs fed screened pellets had improved ($P < 0.004$) F/G compared with pigs fed meal or poor-quality pellets.

Experiment 2

The narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 52, 61, and 57%, respectively (Figures 7, 8, and 9, respectively). The wide feeder adjustment pan coverage scores were 98, 99, and 97% for the meal, poor-quality pellets, and screened pellet diets, respectively (Figures 10, 11, and 12, respectively). When percentage fines were measured, the poor-quality pellets contained 64% pellets and 37% fines, whereas the screened pelleted diet was 95% pellets and 5% fines.

No interactions ($P > 0.10$) were observed between feeder gap adjustment and diet form for pig performance (Table 7). Overall (d 0 to 28), pigs fed from the wide feeder adjustment had increased ($P < 0.03$) ADG and ADFI (Table 8). Feed efficiency did not differ ($P > 0.70$) among pigs fed from the different feeder gap adjustments. Pigs fed screened pellets or poor-quality pellets had increased ($P < 0.03$) ADG compared with pigs fed the meal diet (Table 9). No difference ($P > 0.25$) in ADFI was observed among pigs fed different diet forms. Similar to Exp. 1, pigs fed screened pellets had improved ($P < 0.01$) F/G compared with pigs fed meal or poor-quality pellets.

In Exp. 1, no difference was detected in ADG or ADFI between pigs fed from different feeder adjustments; however, in Exp. 2, pigs fed from the wide feeder gap adjustment had increased ADG and ADFI. For F/G, both experiments agree that feeder adjustment did not significantly influence feed efficiency; therefore, the combined results suggest that feeding nursery pigs from a wide feeder gap may provide benefits in ADG and ADFI with no negative effects on F/G. These results were unexpected, because the feeder pan was almost completely covered with the wide feeder adjustment and feed wastage was expected. With feeders used in this experiment, excessive feed in the pan did not appear to result in additional feed wastage.

For unknown reasons, pigs fed the meal diet in Exp. 1 had increased ADG and ADFI compared with pigs fed both pelleted diets. In contrast, pigs fed the meal diet in Exp. 2 had decreased ADG and ADFI relative to pigs fed the pelleted diets. Despite the differences in ADG and ADFI, both experiments agree that an improvement in F/G was observed only in pigs fed diets with screened pellets and not with the poor-quality pellets; thus, to obtain maximum benefits in feed efficiency from pelleting, the percentage of fines in the diets must be minimized.

Table 1. Diet composition (as-fed basis)

Item	Exp. 1	Exp. 2
Ingredient, %		
Corn	42.78	48.26
Soybean meal (46.5% CP)	30.95	27.10
Dried distillers grains with solubles	20.00	20.00
Soybean oil	3.00	---
Choice white grease	---	1.30
Monocalcium phosphate (21% P)	0.60	0.60
Limestone	1.25	0.87
Salt	0.35	0.50
Trace mineral premix	0.15	0.075
Vitamin premix	0.25	0.030
Copper sulfate	---	0.066
L-lysine HCl	0.375	0.402
DL-methionine	0.060	---
Methionine hydroxyl analog	---	0.120
L-threonine	0.070	0.092
Phytase[1]	0.165	0.040
Antibiotic[2]	---	0.400
AMMO curb[3]	---	0.100
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.30	1.20
Isoleucine:lysine	64	62
Leucine:lysine	146	141
Methionine:lysine	33	34
Met & Cys:lysine	58	58
Threonine:lysine	62	62
Tryptophan:lysine	17.6	18
Valine:lysine	73	73
Total lysine, %	1.50	1.35
ME, kcal/lb	1,573	1,501
CP, %	23.9	21.9
Ca, %	0.71	0.68
P, %	0.60	0.59
Available P, %	0.43	0.31

[1] For Exp. 1, Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 450 phytase units (FTU)/lb, with a release of 0.13% available P. For Exp. 2, Natuphos 2500 (BASF Corporation, Florham Park, NJ), provided 450 FTU/lb, with a release of 0.13% available P.
[2] Chlortetracycline (CTC-50).
[3] Propionic acid-based mold inhibitor (Kemin Industries Inc., Des Moines, IA).

Table 2. Analysis of pan coverage (Exp. 1 and 2)

	Maximum feeder gap opening					
	0.75 in.			1.25 in.		
Item	Meal	70% pellet + 30% fine	Screened pellet	Meal	70% pellet + 30% fine	Screened pellet
Pan coverage, %[1]						
Experiment 1	42	46	37	92	98	93
Experiment 2	52	61	57	98	99	97

[1] Pictures were taken of feeder pan coverage on d 21 and 28 for Exp. 1 and 2, respectively. The feeder pan pictures were then scored by a panel of 5 for percentage of pan coverage.

Table 3. Analysis of percentage fines of pelleted diets (Exp. 1 and 2)[1]

Item	50% pellet + 50% fine	Screened pellet
Percentage fines[2]		
Experiment 1	33	3
Experiment 2	37	5

[1] Feed samples were taken at the feeder and pooled throughout the entire trial.
[2] Fines were characterized as material that would pass through a #6 sieve (3,360 μm openings).

Table 4. Effect of diet form and feeder adjustment on nursery pig growth performance, Exp. 1[1]

	Maximum feeder gap opening								
	0.75 in			1.25 in				Probability, $P<$[2]	
	Meal	70% pellet + 30% fine	Screened pellet	Meal	70% pellet + 30% fine	Screened pellet	SEM	Diet form[3]	Narrow vs. wide
d 0 to 21									
ADG, lb	1.35	1.31	1.30	1.43	1.30	1.31	0.021	0.001	0.13
ADFI, lb	2.00	1.92	1.86	2.13	1.93	1.87	0.043	0.001	0.18
F/G	1.49	1.47	1.43	1.50	1.48	1.43	0.021	0.004	0.73
Weight, lb									
d 0	26.2	26.2	26.2	26.2	26.2	26.2	0.502	0.80	0.65
d 21	54.5	53.6	53.6	56.1	53.6	53.7	0.822	0.61	0.22

[1] A total of 210 nursery pigs (PIC 1050 × 327) were used with 7 pigs per pen and 5 pens per treatment.
[2] No interactions were observed among treatments ($P > 0.05$).
[3] Contrast compares the mean of pigs fed meal, poor-quality pellets, and screened pellets.

Table 5. Main effects of feeder adjustment on nursery pig growth performance (Exp. 1)[1]

	Maximum feeder gap opening			
	0.75 in.	1.25 in.	SEM	Probability, *P*<
d 0 to 21				
ADG, lb	1.32	1.35	0.012	0.13
ADFI, lb	1.93	1.98	0.025	0.18
F/G	1.46	1.47	0.012	0.73
Weight, lb				
d 0	26.2	26.2	0.359	0.65
d 21	53.9	54.5	0.439	0.22

[1] A total of 210 nursery pigs (PIC 1050 × 327) were used with 7 pigs per pen and 5 pens per treatment.

Table 6. Main effects of diet form on nursery pig growth performance (Exp. 1)[1]

	Meal	70 % pellet + 30% fines	Pellet	SEM	Probability, *P*<
d 0 to 21					
ADG	1.39[a]	1.31[b]	1.31[b]	0.015	0.001
ADFI	2.07[a]	1.86[b]	1.93[b]	0.031	0.001
F/G	1.49[b]	1.48[b]	1.43[a]	0.015	0.004
Weight, lb					
d 0	26.2	26.2	26.2	0.435	0.80
d 21	55.3	54.9	53.7	0.733	0.38

[a,b] Means with different superscripts differ significantly, $P < 0.05$.
[1] A total of 210 nursery pigs (PIC 1050 × 327) were used, with 7 pigs per pen and 5 pens per treatment.

Table 7. Effect of diet form and feeder adjustment on nursery pig growth performance, Exp. 2[1]

	Maximum feeder gap opening								
	0.75 in.			1.25 in.				Probability, *P*<[2]	
	Meal	70% pellet + 30% fine	Screened pellet	Meal	70% Pellet + 30% fine	Screened pellet	SEM	Diet form[3]	Narrow vs. wide
d 0 to 28									
ADG, lb	1.52	1.57	1.59	1.58	1.62	1.63	0.016	0.03	0.02
ADFI, lb	2.41	2.46	2.40	2.51	2.55	2.46	0.032	0.25	0.03
F/G	1.59	1.56	1.51	1.59	1.57	1.51	0.010	0.01	0.70
Weight, lb									
d 0	31.2	31.1	31.2	31.2	31.1	31.1	0.61	0.98	0.93
d 28	73.7	75.2	75.7	75.4	76.5	76.8	0.99	0.05	0.02

[1] A total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars) were used, with 25 pigs per pen and 7 pens per treatment.
[2] No interactions were observed between treatments ($P > 0.05$).
[3] Compares the main effect of diet form (meal vs. poor-quality pellet vs. screened pellet).

Table 8. Main effects of feeder adjustment on nursery pig growth performance, Exp. 2[1]

	Maximum feeder gap opening			
	0.75 in.	1.25 in.	SEM	Probability, *P*<
d 0 to 28				
ADG, lb	1.56	1.61	0.020	0.02
ADFI, lb	2.42	2.51	0.033	0.03
F/G	1.55	1.56	0.019	0.70
Weight, lb				
d 0	31.2	31.1	0.581	0.93
d 28	74.9	76.2	0.880	0.02

[1] A total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars) were used, with 25 pigs per pen and 7 pens per treatment.

Table 9. Main effects of diet form on nursery pig growth performance, Exp. 2[1]

	Meal	70% pellet + 30% fines	Pellet	SEM	Probability, *P*<
d 0 to 28					
ADG	1.55[a]	1.60[b]	1.61[b]	0.021	0.03
ADFI	2.46	2.50	2.43	0.051	0.25
F/G	1.59[b]	1.57[b]	1.51[a]	0.024	0.01
Weight, lb					
d 0	31.2	31.1	31.1	0.602	0.98
d 28	74.6[a]	75.9[b]	76.2[b]	0.888	0.05

[a,b] Means with different superscripts differ significantly, $P < 0.05$.
[1] A total of 1,005 nursery pigs (Fast × PIC sows × TR4 boars) were used, with 25 pigs per pen and 7 pens per treatment.

Figure 1. Narrow feeder adjustment with meal diet (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 42% feeder pan coverage.

Figure 2. Narrow feeder adjustment with 70% pellets + 30% fines (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 46% feeder pan coverage.

Figure 3. Narrow feeder adjustment with screened pellets (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 37% feeder pan coverage.

Figure 4. Wide feeder adjustment with meal diet (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 92% feeder pan coverage.

Figure 5. Wide feeder adjustment with 70% pellets + 30% fines (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 98% feeder pan coverage.

Figure 6. Wide feeder adjustment with screened pellets (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 93% feeder pan coverage.

Figure 7. Narrow feeder adjustment with meal diet (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 52% feeder pan coverage.

Figure 8. Narrow feeder adjustment with 70% pellets + 30% fines (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 61% feeder pan coverage.

Figure 9. Narrow feeder adjustment with screened pellets (minimum feeder gap was 0.50 in. with a maximum gap of 0.75 in.) averaged 57% feeder pan coverage.

Figure 10. Wide feeder adjustment with meal diet (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 98% feeder pan coverage.

Figure 11. Wide feeder adjustment with 70% pellets + 30% fines (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 99% feeder pan coverage.

Figure 12. Wide feeder adjustment with screened pellets (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 97% feeder pan coverage.

Effects of Diet Form and Feeder Adjustment on Growth Performance of Growing-Finishing Pigs[1]

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Summary

A total of 252 pigs (PIC 327 × 1050, initially 125.2 lb BW) were used in a 69-d trial to determine the effects of diet form and feeder adjustment on growth performance of growing-finishing pigs. Treatments were arranged in a 2 × 3 factorial with the main effects of feeder adjustment and diet form. The 2 feeder adjustments were a narrow feeder adjustment (minimum gap opening of 0.50 in.) and a wide adjustment (minimum gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75 or 1.25 in. for the narrow and wide adjustments, respectively. The 3 diet forms were meal, poor-quality pellets (50% pellets and 50% fines), and screened pellets with minimal fines. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 12, 22, 39, 48, and 69. No diet form × feeder adjustment interactions were observed ($P > 0.24$). For Phases 1 (d 0 to 22) and 2 (d 22 to 48), feeder adjustment did not influence ($P > 0.28$) ADG, but ADFI tended to increase ($P < 0.07$) and F/G worsened ($P < 0.05$) for pigs fed from the wide adjusted feeders. In Phase 3 (d 48 to 69), no differences were detected in growth performance ($P > 0.17$) between pigs fed from either feeder adjustment.

Overall (d 0 to 69), ADG did not differ between pigs fed from the 2 feeder adjustments, but ADFI decreased ($P < 0.03$) and F/G was improved ($P < 0.03$) for pigs fed from the narrow adjusted feeders. The response to diet form was similar among phases, with pigs fed meal diets having decreased ($P < 0.05$) overall ADG compared with pigs fed the screened pelleted diets and with those fed poor-quality pellets intermediate. Feeding screened pellets resulted in decreased ($P < 0.004$) ADFI and improved ($P < 0.001$) F/G compared with pigs fed meal diets, with those fed poor-quality pellets intermediate.

In conclusion, reducing feeder gap to manage feeder pan coverage helped to reduce feed wastage and improve feed efficiency. Also, feeding pelleted diets improved feed efficiency in all phases, but the magnitude of improvement was greatest when the percentage of fines in the diet was minimized.

Key words: diet form, feeder adjustment, pellet, finishing pig

Introduction

With the increasing cost of cereal grains, the need to minimize feed wastage and improving feed efficiency is becoming more apparent in the swine industry. Two

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methods that have shown benefits in F/G are managing feeder adjustment and pelleting swine diets; however, little research has been conducted to investigate the relationship between these two methods. Previous research has suggested that feeder adjustment has little influence on feed wastage for nursery pigs (see "Effect of Diet Form and Feeder Adjustment on Growth Performance of Nursery Pigs," p. 278). Conversely, experiments with growing-finishing pigs have shown that feed wastage can be minimized and F/G improved with proper feeder adjustment (Bergstrom et al., 2010[4]; Myers et al., 2010a[5]b[6]). Pelleting diets also has been shown to improve F/G, but the magnitude of improvement is influenced by pellet quality and the percentage of fines in the feed. More research is required to optimize feed efficiency and determine the relationship between feeder gap adjustment and diet form. Thus, the objective of this experiment was to determine the effects of feeder adjustment and diet form on growth performance of growing-finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (8 ft × 10 ft). Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

A total of 245 pigs (PIC 327 × 1050, initially 125.2 lb BW) were used in a 69-d trial. Pens were randomly allotted to 1 of 6 experimental treatments. There were 5 pens per treatment with 7 pigs per pen and 1 replicate with 6 pigs per pen. To ensure equal floor space among pens of 7 and 6 pigs, the gating was adjusted to provide 8 ft^2/pig during the study. Treatments were arranged in a 2 × 3 factorial with the main effects of feeder adjustment and diet form. The 2 feeder adjustments were a narrow adjustment (minimum gap opening of 0.50 in.) and a wide adjustment (minimum gap opening of 1.00 in.). The feeders were adjusted to the minimum gap setting, but the agitation plate could be moved upward to a maximum gap opening of 0.75 or 1.25 in. for the narrow and wide adjustment, respectively. The 3 diet forms were meal, poor-quality pellets (50% pellets and 50% fines), and screened pellets with minimal fines. Common diets containing 20% DDGS were fed in 3 phases from d 0 to 22, d 22 to 48, and d 48 to 69 (Table 1). Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feed disappearance on d 0, 12, 22, 39, 48, and 69. Pictures were taken of feeder pan coverage once during each phase. The feeder pan pictures were then scored by a panel of 5 evaluators for percentage of pan coverage (Table 2).

Diets were prepared and pelleted at Hubbard Feeds in Atlantic, IA. Pellets were manufactured and fines were screened off and collected. After the screened pelleted diet was

[4] Bergstrom et al., Swine Day 2010, Report of Progress 1038, pp. 190–200.
[5] Myers et al., Swine Day 2010, Report of Progress 1038, pp. 166–171.
[6] Myers et al., Swine Day 2010, Report of Progress 1038, pp. 172–177.

bagged, the fines were added back to the remaining pellets. The mixture of pellets and fines was then passed through the roller mill to create the additional fines required for the poor-quality pellets. Feed samples were taken at the feeder during each phase. At the end of the experiment, percentage fines were measured on a composite of feed for pelleted diets from each phase. Fines were characterized as material that would pass through a #6 sieve (3,360-μm openings).

Experimental data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatments were arranged as a 2 × 3 factorial with 2 feeder adjustments and 3 diet forms. Differences between treatments were determined using the PDIFF statement in SAS. Significant differences were declared at $P < 0.05$ and trends were declared at $P < 0.10$.

Results and Discussion

No interactions were observed between feeder adjustment and diet form during any of the dietary phases or for the overall study.

For Phase 1 (d 0 to 22), the narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 31, 49, and 44%, respectively (Figures 1, 2, and 3, respectively). The wide feeder adjustment pan coverage scores were 83, 96, and 86% for the meal, poor-quality pellets, and screened pellets diets, respectively (Figures 4, 5, and 6, respectively). When percentage fines were measured, the Phase 1 poor-quality pellets that were originally intended to contain 50% pellets and 50% fines actually contained 56% pellets and 44% fines (Table 3). The screened pelleted diet was 92% pellets and 8% fines. During Phase 1, there was no difference ($P > 0.61$) in ADG among pigs fed from feeders with the different adjustment settings (Tables 4 and 5). Pigs fed from feeders with the wide adjustment tended to have increased ($P < 0.07$) ADFI, which resulted in poorer ($P < 0.02$) F/G compared with pigs fed from feeders with the narrow adjustment. For diet form, ADG did not differ ($P > 0.32$) among treatments (Table 6). Pigs fed the meal diet had increased ($P < 0.04$) ADFI compared with pigs fed the poor quality pellets or screened pellets. Diet form had a significant impact on F/G during Phase 1, with pigs fed the meal diet having poorer ($P < 0.03$) F/G than pigs fed screened pellets, with those fed poor-quality pellets intermediate.

During Phase 2 (d 22 to 48), the narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 62, 77, and 69%, respectively (Figures 7, 8, and 9, respectively). The wide feeder adjustment pan coverage scores were 90, 99, and 92% for the meal, poor-quality pellets, and screened pellets diets, respectively (Figures 10, 11, and 12, respectively). The Phase 2 poor-quality pelleted diet contained 48% pellets and 52% fines, whereas the screened pelleted diet was 92% pellets and 8% fines. There was no difference ($P > 0.28$) in ADG among pigs fed from feeders with the different adjustment settings. Pigs fed from feeders with the wide adjustment had greater ($P < 0.02$) ADFI and poorer ($P < 0.05$) F/G than pigs fed from feeders with the narrow adjustment. For diet form, the pigs fed 50% pellets + 50% fines unexpectedly tended to have increased ($P < 0.06$) ADG compared with pigs fed either of the other 2 diet form treatments. Pigs fed the meal or poor-quality pelleted diets had increased ($P < 0.002$) ADFI compared with pigs fed the screened pellets. The response to diet form on feed efficiency was identical to Phase 1, in which pigs fed the screened pellets had the best ($P < 0.001$) F/G, pigs fed the meal diet had the poorest F/G, and pigs fed poor-quality pellets were intermediate.

The Phase 3 (d 48 to 69) narrow feeder adjustment pan coverage scores for the meal, poor-quality pellets, and screened pellets diets were 89, 93, and 92%, respectively (Figures 13, 14, and 15, respectively). The wide feeder adjustment pan coverage scores were 95, 99, and 96% for the meal, poor-quality pellets, and screened pellets diets, respectively (Figures 16, 17, and 18, respectively). The Phase 3 poor-quality pellets contained 45% pellets and 55% fines, whereas the screened pelleted diet was 90% pellets and 10% fines. There was no difference ($P > 0.17$) in ADG, ADFI, or F/G between pigs fed from feeders with the different adjustment settings during the final phase, although the numerical trends for ADFI and F/G were similar to previous phases. For diet form, pigs fed the meal diet had decreased ($P < 0.04$) ADG compared with pigs fed either of the pelleted diets, and pigs fed the pelleted diet had decreased ($P < 0.02$) ADFI compared with pigs fed the meal or poor-quality pellets. Similar to the previous 2 periods, pigs fed the screened pellets had the best ($P < 0.001$) F/G, pigs fed the meal diet had the poorest F/G, and pigs fed poor-quality pellets were intermediate.

Overall (d 0 to 69), feeder adjustment had no effect ($P > 0.46$) on ADG. Responses from Phases 1 and 2 carried over into the overall data, resulting in decreased ($P < 0.03$) ADFI and improved ($P < 0.03$) F/G in pigs fed from the narrow adjusted feeders. Pigs fed meal diets had decreased ($P < 0.05$) ADG compared with pigs fed the screened pelleted diets, with pigs fed poor-quality pellets intermediate. Feeding screened pellets resulted in decreased ($P < 0.004$) ADFI compared with pigs fed poor-quality pellets or meal diets. Consistent in all 3 phases, pigs fed screened pellets had improved ($P < 0.001$) F/G compared with pigs fed the meal diet, and those fed poor-quality pellets were intermediate.

In summary, feeder adjustment did not influence ADG in this study. This lack of response is probably due to the relatively high feeder pan coverage on the narrow feeder adjustment. Increasing pan coverage further with the wide adjustment increased feed wastage and resulted in poorer F/G. At the same feeder setting, feeder pan coverage scores increased over time for the narrow feeder setting. This may explain why a significant benefit in F/G was observed for the narrow feeder adjustment during the first two phases, but not during the final phase. Thus, monitoring feeder gap opening to properly manage feeder pan coverage can help minimize feed wastage and improve feed efficiency in finishing pigs. This result seems to suggest that decreased feeder gap opening should be used for feeding heavier weight pigs. As expected, diet form also had a significant impact on F/G, because pigs fed the meal diet had the poorest F/G, pigs fed screened pellets had the best F/G, and pigs fed poor-quality pellets were intermediate. This confirms previous research that feeding pelleted diets improves feed efficiency, but the magnitude of improvement was greatest when the percentage of fines in the diet was minimized.

Table 1. Diet composition (as-fed basis)

Item	Phase 1[1]	Phase 2[2]	Phase 3[3]
Ingredient, %			
Corn	59.76	63.08	76.04
Soybean meal (46.5% CP)	17.05	14.00	11.65
Dried distillers grains with solubles	20.00	20.00	10.00
Choice white grease	1.35	1.15	0.75
Limestone	1.01	0.99	0.85
Salt	0.35	0.35	0.35
Trace mineral premix	0.10	0.10	0.09
Vitamin premix	0.03	0.03	0.03
L-lysine HCl	0.30	0.25	0.20
Selenium (0.2% Se)	0.015	0.015	0.015
Phytase[4]	0.041	0.041	0.041
Total	100	100	100
Calculated analysis			
Standardized ileal digestible amino acids, %			
Lysine	0.90	0.79	0.67
Isoleucine:lysine	68	71	71
Leucine:lysine	172	188	189
Methionine:lysine	32	35	35
Met & Cys:lysine	62	68	69
Threonine:lysine	55	64	64
Tryptophan:lysine	18	19	19
Valine:lysine	83	88	88
Total lysine, %	1.04	0.92	0.77
ME, kcal/lb	1,520	1,520	1,523
CP, %	17.7	16.5	13.7
Ca, %	0.48	0.47	0.40
P, %	0.42	0.40	0.35
Available P, %	0.26	0.25	0.25

[1] Phase 1 diets were fed from d 0 to 22.
[2] Phase 2 diets were fed from d 22 to 48.
[3] Phase 3 diets were fed from d 48 to 69.
[4] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 460 phytase units (FTU)/lb, with a release of 0.13% available P.

Table 2. Analysis of pan coverage

	Maximum feeder adjustment					
	0.75 in.			1.25 in.		
Item	Meal	50% pellet + 50% fine	Screened pellet	Meal	50% pellet + 50% fine	Screened pellet
Pan coverage, %[1]						
Phase 1	31	49	44	83	96	86
Phase 2	62	77	69	90	99	92
Phase 3	89	93	92	95	99	96

[1] Pictures were taken of feeder pan coverage once during each phase. The feeder pan pictures were then scored by a panel of 5 evaluators for percentage of pan coverage.

Table 3. Analysis of percentage fines of pelleted diets[1]

Item	50% pellet + 50% fine	Screened pellet
Percentage fines, %[2]		
Phase 1	44	8
Phase 2	52	8
Phase 3	55	10

[1] Feed samples were taken at the feeder during each phase.
[2] Fines were characterized as material that would pass through a #6 sieve (3,360-µm openings).

Table 4. Effect of diet form and feeder adjustment on growing-finishing pig growth performance[1]

	Maximum feeder adjustment								
	0.75 in.			1.25 in.				Probability, $P<$[2]	
	Meal	50% pellet + 50% fine	Screened pellet	Meal	50% pellet + 50% fine	Screened pellet	SEM	Diet form[3]	Narrow vs. wide
d 0 to 22									
ADG, lb	2.13	2.06	2.20	2.16	2.12	2.19	0.065	0.32	0.61
ADFI, lb	5.06	4.69	4.75	5.30	5.06	4.84	0.151	0.04	0.07
F/G	2.37	2.27	2.17	2.45	2.38	2.22	0.040	0.001	0.02
d 22 to 48									
ADG, lb	2.16	2.32	2.22	2.26	2.32	2.25	0.046	0.06	0.28
ADFI, lb	5.94	5.78	5.46	6.36	6.29	5.58	0.168	0.002	0.02
F/G	2.76	2.49	2.46	2.83	2.72	2.48	0.061	0.001	0.05
d 48 to 69									
ADG, lb	2.00	2.19	2.22	2.07	2.16	2.20	0.070	0.04	0.93
ADFI, lb	7.18	7.33	6.84	7.85	7.50	6.82	0.240	0.02	0.17
F/G	3.60	3.35	3.09	3.80	3.49	3.10	0.113	0.001	0.20
d 0 to 69									
ADG, lb	2.10	2.20	2.21	2.17	2.21	2.21	0.043	0.08	0.46
ADFI, lb	6.04	5.89	5.64	6.47	6.25	5.72	0.159	0.004	0.03
F/G	2.87	2.68	2.55	2.98	2.83	2.58	0.053	0.001	0.03
BW, lb									
d 0	125.2	125.2	125.2	125.2	125.1	125.2	2.62	0.99	0.99
d 22	172.1	172.4	173.4	173.3	171.8	173.6	3.33	0.91	0.93
d 48	228.2	232.8	232.4	231.6	233.2	232.1	4.10	0.73	0.89
d 69	270.2	280.4	279.0	275.0	278.5	278.3	4.67	0.29	0.85

[1] A total of 252 finishing pigs (PIC 327 × 1050) were used with 7 pigs per pen and 6 pens per treatment.
[2] No interactions were observed between treatments ($P > 0.05$).
[3] Compares the main effect of diet form (comparing meal vs. poor-quality pellet vs. screened pellet).

Table 5. Main effects of feeder adjustment on growing-finishing pig growth performance[1]

	Maximum feeder adjustment			
	0.75 in.	1.25 in.	SEM	Probability, *P*<
d 0 to 22				
ADG, lb	2.13	2.16	0.037	0.61
ADFI, lb	4.83	5.07	0.087	0.07
F/G	2.27	2.35	0.023	0.02
d 22 to 48				
ADG, lb	2.23	2.27	0.027	0.28
ADFI, lb	5.73	6.08	0.097	0.02
F/G	2.57	2.67	0.035	0.05
d 48 to 69				
ADG, lb	2.14	2.14	0.040	0.93
ADFI, lb	7.11	7.39	0.138	0.17
F/G	3.35	3.47	0.065	0.20
d 0 to 69				
ADG, lb	2.17	2.20	0.025	0.46
ADFI, lb	5.85	6.15	0.092	0.03
F/G	2.70	2.80	0.031	0.03
Weight, lb				
d 0	125.2	125.2	1.51	0.99
d 22	172.7	172.9	1.92	0.93
d 48	231.1	232.3	2.37	0.89
d 69	276.5	277.2	2.70	0.85

[1]A total of 252 finishing pigs (PIC 327 × 1050) were used with 7 pigs per pen and 6 pens per treatment.

Table 6. Main effects of diet form on growing-finishing pig growth performance[1]

	Meal	50% pellet + 50% fines	Screened pellet	SEM	Probability, *P*<
d 0 to 22					
ADG, lb	2.15	2.09	2.19	0.046	0.32
ADFI, lb	5.18[a]	4.87[b]	4.80[b]	0.107	0.04
F/G	2.41[a]	2.33[b]	2.19[c]	0.028	0.001
d 22 to 48					
ADG, lb	2.21[a]	2.32[b]	2.24[a]	0.033	0.06
ADFI, lb	6.15[a]	6.04[a]	5.52[b]	0.119	0.002
F/G	2.79[a]	2.61[b]	2.47[c]	0.043	0.001
d 48 to 69					
ADG, lb	2.03[a]	2.18[b]	2.21[b]	0.049	0.04
ADFI, lb	7.51[a]	7.41[a]	6.83[b]	0.169	0.02
F/G	3.70[a]	3.42[b]	3.10[c]	0.080	0.001
d 0 to 69					
ADG, lb	2.14[a]	2.20[ab]	2.21[b]	0.030	0.08
ADFI, lb	6.25[a]	6.07[a]	5.68[b]	0.113	0.004
F/G	2.93[a]	2.76[b]	2.57[c]	0.038	0.001
Weight, lb					
d 0	125.2	125.1	125.2	1.85	0.99
d 22	172.7	172.1	173.5	2.35	0.91
d 48	229.9	233.0	232.3	2.90	0.73
d 69	272.6	279.5	278.6	3.30	0.29

[1] A total of 252 finishing pigs (PIC 327 × 1050) were used with 7 pigs per pen and 6 pens per treatment.
[a,b,c] Means on the same row with different superscripts differ, $P < 0.05$.

Figure 1. Phase 1 narrow feeder adjustment with meal diet (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 31% feeder pan coverage.

Figure 2. Phase 1 narrow feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 49% feeder pan coverage.

Figure 3. Phase 1 narrow feeder adjustment with screened pellets (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 44% feeder pan coverage.

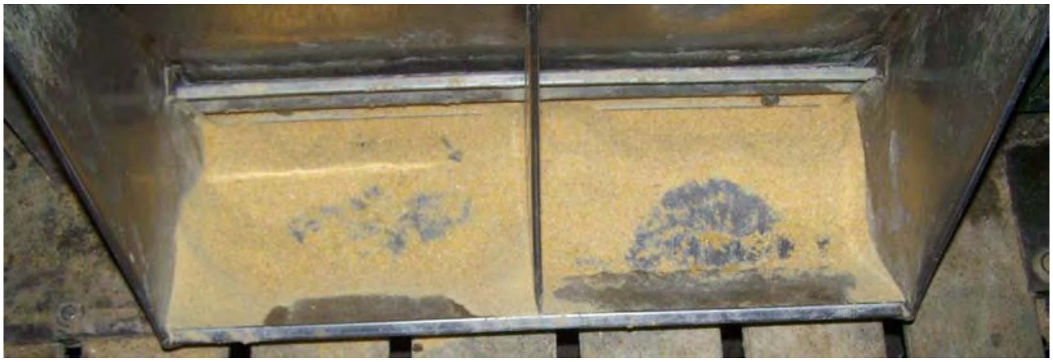

Figure 4. Phase 1 wide feeder adjustment with meal diet (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 83% feeder pan coverage.

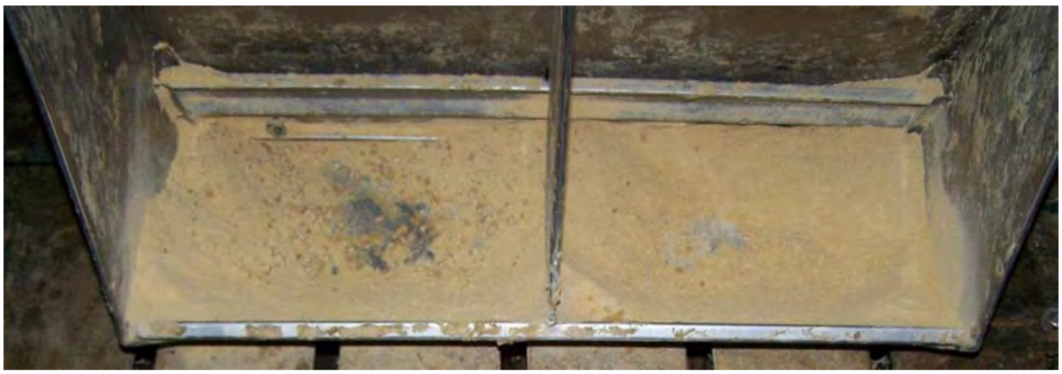

Figure 5. Phase 1 wide feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 96% feeder pan coverage.

Figure 6. Phase 1 wide feeder adjustment with screened pellets (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 86% feeder pan coverage.

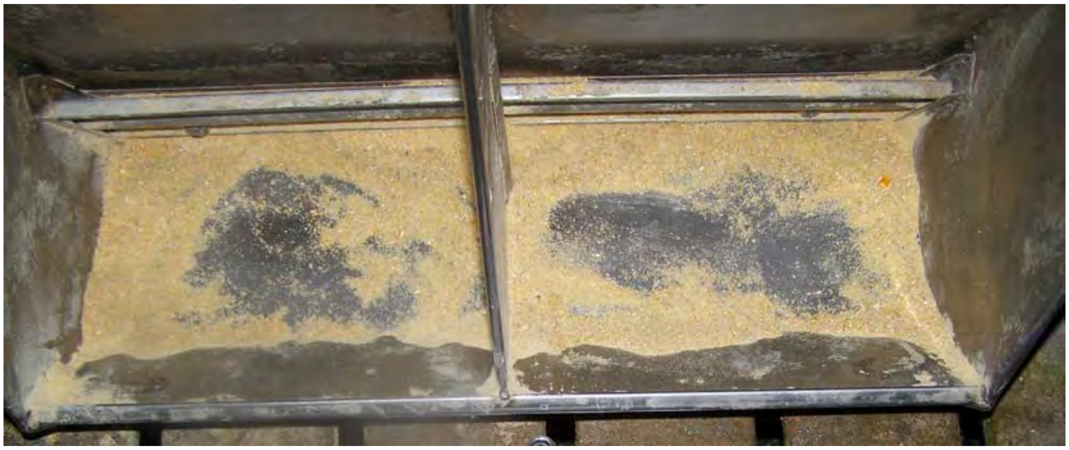

Figure 7. Phase 2 narrow feeder adjustment with meal diet (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 62% feeder pan coverage.

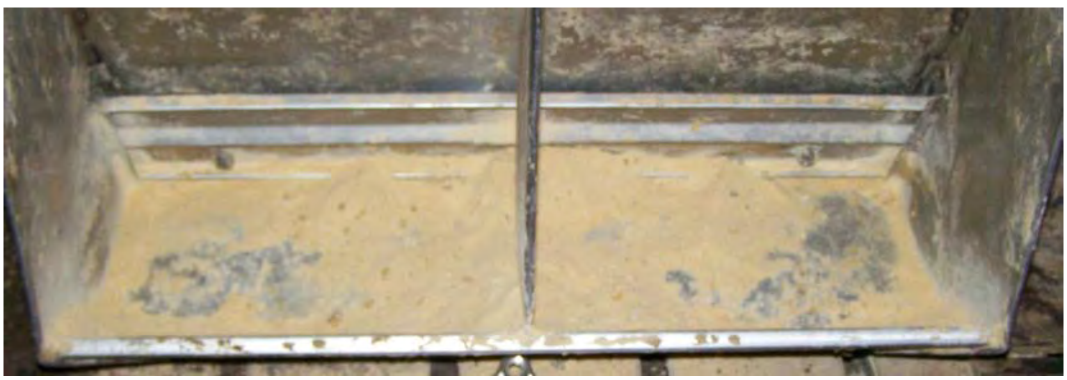

Figure 8. Phase 2 narrow feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 77% feeder pan coverage.

Figure 9. Phase 2 narrow feeder adjustment with screened pellets (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 69% feeder pan coverage.

Figure 10. Phase 2 wide feeder adjustment with meal diet (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 90% feeder pan coverage.

Figure 11. Phase 2 wide feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 99% feeder pan coverage.

Figure 12. Phase 2 wide feeder adjustment with screened pellets (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 92% feeder pan coverage.

Figure 13. Phase 3 narrow feeder adjustment with meal diet (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 89% feeder pan coverage.

Figure 14. Phase 3 narrow feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 93% feeder pan coverage.

Figure 15. Phase 3 narrow feeder adjustment with screened pellets (minimum feeder gap was 0.5 in. with a maximum gap of 0.75 in.) averaged 92% feeder pan coverage.

Figure 16. Phase 3 wide feeder adjustment with meal diet (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 95% feeder pan coverage.

Figure 17. Phase 3 wide feeder adjustment with 50% pellets and 50% fines (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 99% feeder pan coverage.

Figure 18. Phase 3 wide feeder adjustment with screened pellets (minimum feeder gap was 1.00 in. with a maximum gap of 1.25 in.) averaged 96% feeder pan coverage.

Effects of Feeding Varying Ingredient Particle Sizes and Diet Forms for 25- to 50-lb Nursery Pigs on Performance, Caloric Efficiency, and Economics[1,2]

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Summary

A total of 675 pigs (PIC 1050 barrows; initially 24.5 lb BW and 37 d of age) were used in a 21-d study to determine the effects of feeding varying ingredient particle sizes and diet form for 25- to 50-lb nursery pigs on performance, caloric efficiency, and economics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 8 dietary treatments with 17 replications per treatment and 5 pigs per pen in two groups of nursery pigs. The 8 experimental diets included 3 corn-soybean meal–based diets consisting of: (1) corn fraction ground to an average of 620 µ and fed in meal form, (2) corn fraction ground to an average of 352 µ and fed in meal form, and (3) diet 2 but pelleted. The remaining 5 diets were high by-product diets containing 20% wheat middlings (midds) and 30% dried distillers grains with solubles (DDGS). Diets 4 to 8 consisted of: (4) corn fraction ground to an average of 620 µ, midds and DDGS unground from the plant with an average particle size of 534 µ and 701 µ, respectively, and fed in meal form; (5) diet 4 but corn fraction ground to an average of 352 µ and fed in meal form; (6) diet 5 but fed in pellet form; (7) corn, soybean meal, DDGS, and midds ground to average particle sizes of 352 µ, 421 µ, 377 µ, and 357 µ, respectively, fed in meal form; and (8) diet 7 but fed in pellet form. The two formulated diets were not balanced for energy, so energy was lower for treatments 4 to 8 than for treatments 1 to 3.

Overall (d 0 to 21), pigs fed pelleted diets had improved ($P < 0.03$) ADG, F/G, and caloric efficiency when measured on an ME or NE basis. Reducing the particle size of the corn did not influence F/G or caloric efficiency, but tended ($P < 0.08$) to reduce ADFI, which led to a reduction ($P < 0.02$) in ADG. Pigs fed the high-by-product diet had reduced ($P < 0.001$) ADG, ADFI, and final BW and poorer ($P < 0.01$) F/G, but caloric efficiency similar to pigs fed the corn-soybean meal–based diet. Grinding the by-products to a smaller particle size further reduced ($P < 0.05$) ADG, ADFI, and final BW but did not influence feed efficiency.

For economics, although feed cost per pig tended to decrease ($P < 0.09$) when corn was finely ground or when all ingredients were finely ground, it was reduced ($P < 0.0001$) enough only for pigs fed the high-by-product diet to result in a reduction ($P < 0.001$) in feed cost per pound of gain. Because of reduced total revenue per pig, pigs fed

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[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

[4] Department of Grain Sciences and Industry, College of Agriculture, Kansas State University.

high-by-product diets had income over feed cost (IOFC) similar to pigs fed the corn-soybean meal–based diet. Fine-grinding all feed ingredients also decreased ($P < 0.0001$) revenue/pig and IOFC. Pelleting was the only processing technology that improved ($P < 0.01$) revenue/pig and IOFC in this trial. Grinding corn finer than 620 µ or grinding other components of the high-by-product diet did not improve nursery pig performance or IOFC; however, pelleting resulted in the expected improvements in pig performance and economic return.

Key words: DDGS, feed processing, nursery pig, wheat middlings

Introduction

Increasing ingredient costs have resulted in swine producers searching for low-priced energy sources to replace corn in diets. Wheat middlings and corn DDGS are both common high-fiber (midds, crude fiber <9.5%; DDGS, crude fiber = 7.3%) by-products of the wheat milling and ethanol industries, respectively. With corn currently trading around $8.00/bu, these two ingredients have become common additions to many swine diets to help lower feed costs. Although traditional DDGS with a fat content greater than 10% has an energy value similar to corn, midds have a lower energy concentration (ME = 1,372 kcal/lb; NRC, 1998[5]).

Processing of individual ingredients or complete diets can provide alternative methods to more efficiently utilize dietary energy from cereal grains or other feedstuffs. Grinding corn from 900 to 300 µ in early nursery phases has been shown to improve ADG, ADFI, and F/G[6]. Pelleting of diets also has been found consistently to improve ADG and F/G, but research evaluating fine-grinding of fibrous feed ingredients or grinding of all major ingredients fed in the same diet has been limited; therefore, the objective of this study was to determine the effects of feeding various ingredient particle sizes and diet forms on growth performance, caloric efficiency, and economics of nursery pigs from 25 to 50 lb.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Segregated Early Weaning Facility in Manhattan, KS.

A total of 675 pigs (PIC 1050 barrows; initially 24.5 lb BW and 37 d of age) were used in a 21-d study. Pigs were allotted to pens by initial BW, and pens were assigned to treatments in a completely randomized design with 5 pigs per pen and 17 replications per treatment. Two groups of pigs were used with 8 replications in one group and 9 replications in the second group. The two formulated diets included a corn-soybean meal–based control diet and a negative control diet containing 20% midds and 30% DDGS (Table 1). The 8 experimental diets included the corn-soybean meal–based diets with: (1) corn fraction ground to an average of 620 µ and diet fed in meal form, (2) corn fraction ground to an average of 352 µ and diet fed in meal form, and (3) diet 2 but pelleted. The remaining 5 diets were the high-by-product diet with treat-

[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[6] Healy, B. J. 1994. Optimum particle size of corn and hard and soft sorghum for nursery pigs. J. Anim. Sci. 72:2227.

ments consisting of: (4) corn fraction ground to an average of 620 µ, midds and DDGS unground from the plant with an average particle size of 534 and 701 µ, respectively, and diet fed in meal form; (5) diet 4 but corn fraction ground to an average of 350 µ and fed in meal form; (6) diet 5 but fed in pellet form; (7) corn, soybean meal, DDGS, and midds ground to average particle sizes of 352, 421, 377, and 357 µ, respectively, fed in meal form; and (8) diet 7 fed in pellet form. For diet formulation, the ME value of DDGS was similar to that of corn (1,551 kcal/kg; NRC 1998[5]), whereas the midds ME value was 1,372 kcal/lb (NRC, 1998). Diets were not formulated on an energy basis, so diet energy was lower for high-by-product treatment diets. All diets were formulated to a constant standardized ileal digestible (SID) lysine level to ensure changes in performance were due to dietary energy differences rather than differences in amino acid concentrations.

Feed was manufactured separately for each group of pigs. For the first group, all ingredients were ground and complete diets were manufactured (meal and pellets) at the K-State Grain Science Feed Mill. For the second group, all ingredients were ground and complete diets were manufactured (meal) at the K-State Grain Science Feed Mill; diets requiring pelleting were transported to Hubbard Feeds (Beloit, KS) for processing. All 620-µ corn was ground by a 3-high roller mill (Model TP 912, Roskamp Manufacturing, Cedar Falls, IA). All ingredients that were finely ground were processed using a full-circle teardrop hammermill (P-240D Pulverator, Jacobsen Machine Works, Minneapolis, MN) with a 1/16-in. screen. Diets for the first group of pigs were pelleted in a 30-horsepower pellet mill (30 HD Master Model, California Pellet Mill, San Francisco) with a 1.25-in.-thick die with 5/32-in. openings. Pellets from the second group were made with an Ace 50, Sprout Waldron Pellet Mill with 11/64-in. openings. Corn was from the same source for both groups of pigs and was split at the mill to be ground through the hammermill or roller mill.

Pigs were provided unlimited access to feed and water by way of a 4-hole dry self-feeder and a cup waterer in each pen (5 ft × 5 ft). Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 of the trial to determine ADG, ADFI, and F/G.

Samples of corn, soybean meal, midds, DDGS, and complete diets were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, crude fiber, fat, ash, Ca, and P (Tables 2 and 3). In addition, bulk density and particle size of the corn, soybean meal, midds, DDGS, and complete diets were determined. Angle of repose for all ingredients and diets in meal form was also determined. For all diets in pelleted form, pellet durability index (PDI), percentage fines, production rate, and hot pellet temperature were obtained (Table 4).

Caloric feed efficiencies were determined on both an ME and NE (INRA, 2004[7]) basis. Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed cost/lb gain, revenue/pig, and IOFC were also calculated. Diet costs were determined with the following ingredient costs: corn = $8.00/bu, soybean meal = $480/ton, midds = $240/ton, and DDGS = $280/ton. Processing costs were as follows: grinding = $5/ton, mixing = $3/ton,

[7] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

delivery and handling = \$7/ton, and pelleting = \$6/ton. Feed cost/pig was determined by total feed intake × diet cost (\$/lb). Feed cost/lb gain was calculated using F/G × diet cost (\$/lb). Revenue/pig was determined by total gain × \$0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Data from both groups were combined and analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Treatment was considered a fixed effect and group as a random effect in the statistical model. Contrasts were used to compare the effects of diet form, corn particle size, diet type (corn soybean meal vs. high by-product), and grinding of all ingredients. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

Results and Discussion

The chemical analyses of the midds, DDGS, soybean meal (SBM), and corn (Table 2) revealed that most nutrients were similar to formulated values. Crude protein was slightly lower for DDGS and SBM than formulated values. Crude fiber levels were lower for midds and SBM but slightly higher for DDGS and corn than formulated values. All ingredients were slightly higher for Ca and P than formulated values. As expected, analysis of the dietary treatments showed increased fiber component levels with the addition of increasing midds and DDGS to the diet. The diet bulk density also decreased when by-products were added to the diet. When similar diets were pelleted, bulk density increased. Angle of repose increased as corn or all ingredients were finely ground, and PDI increased as ingredients were finely ground and by-products were added to the diet. The percentage of fines decreased as ingredients were finely ground and by-products were added to the diet.

Overall (d 0 to 21), pigs fed pelleted diets had improved ($P < 0.03$) ADG, F/G, and caloric efficiency when measured on an ME or NE basis. Reducing the particle size of the corn did not influence F/G or caloric efficiency, but tended ($P < 0.08$) to reduce ($P < 0.08$) ADFI, which led to a reduction ($P < 0.02$) in ADG. Pigs fed the high-by-product diet had reduced ($P < 0.001$) ADG, ADFI, and final BW and poorer ($P < 0.01$) F/G but caloric efficiency similar to pigs fed the corn-SBM–based diet. Grinding the by-products to a smaller particle size further reduced ($P < 0.05$) ADG, ADFI, and final BW but did not influence feed efficiency.

In the economic analysis, although feed cost per pig tended to decrease ($P < 0.09$) when corn was finely ground or when all ingredients were finely ground, it was reduced ($P < 0.0001$) enough only for pigs fed the high-by-product diet to result in a reduction ($P < 0.001$) in feed cost per pound of gain. Because of reduced total revenue per pig, pigs fed high-by-product diets had IOFC similar to pigs fed the corn-SBM–based diet. Fine-grinding all feed ingredients also decreased ($P < 0.0001$) revenue/pig and IOFC. Pelleting was the only processing technology that improved ($P < 0.01$) revenue/pig and IOFC in this trial.

Results from this study suggest that reducing the particle size of either corn or all major ingredients in complete feed when fed in meal form decreased performance in nursery pigs. This result was unexpected. Previous research has consistently shown improvements in feed efficiency as corn particle size is reduced, and reasons for this finding in our study are unknown. Interestingly, as all major ingredients were ground in the high-by-product diet and fed in meal form, feed intake for these pigs was clearly the lowest of all pigs fed diets in meal form, which suggests that feeding a finely ground complete diet may have reduced palatability. Feeders were checked frequently to ensure pigs had ad libitum access to feed and that the ADFI response was not due to feed bridging in feeders.

As expected, pelleting diets in this study improved growth rate, feed efficiency, and caloric efficiency. This improvement could be due to improvements in diet digestibility, because feed intake was not changed. The study also showed that pelleting increased total revenue and IOFC when using a pelleting charge of $6/ton. Numerically, the highest IOFC occurred for treatment 3 (finely ground corn without by-products and pelleted diet).

Fine-grinding resulted in decreased growth rate through reduced feed intake. These data confirm the growth performance benefits of pelleting diets for nursery pigs. In addition, fine-grinding all major ingredients in a high-by-product diet did not improve performance and led to reduced economic returns due to higher processing costs and lack of benefit in growth.

Table 1. Diet composition (as-fed basis)[1]

	DDGS, %:[2]	0	30
Item	Midds, %:	0	20
Ingredient, %			
Corn		63.69	24.59
Soybean meal (46.5% CP)		32.80	22.43
DDGS		---	30.00
Wheat middlings		---	20.00
Monocalcium phosphate (21% P)		1.05	0.05
Limestone		1.00	1.50
Salt		0.35	0.35
Vitamin premix		0.25	0.25
Trace mineral premix		0.15	0.15
L-lysine HCl		0.33	0.48
DL-methionine		0.135	0.005
L-threonine		0.125	0.075
Phytase[3]		0.125	0.125
Titanium[4]		---	---
Total		100.00	100.00

continued

Table 1. Diet composition (as-fed basis)[1]

	DDGS, %:[2]	0	30
Item	Midds, %:	0	20
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lysine		1.28	1.28
Isoleucine:lysine		61	64
Leucine:lysine		129	152
Methionine:lysine		34	28
Met & Cys:lysine		58	58
Threonine:lysine		63	63
Tryptophan:lysine		17.5	17.5
Valine:lysine		68	76
Total lysine, %		1.42	1.46
ME, kcal/lb[5]		1,503	1,476
NE. kcal/lb[6]		1,072	1,036
SID lysine:ME, g/Mcal		3.86	3.93
CP, %		21.1	24.4
Crude fiber, %		2.7	2.8
NDF, %		4.1	9.9
ADF, %		1.6	4.1
Ca, %		0.70	0.70
P, %		0.63	0.63
Available P, %		0.42	0.42

[1] Treatment diets fed for 21 d.
[2] DDGS: dried distillers grains with solubles.
[3] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.
[4] Titanium was included in diets fed from day 7 to 14 in group 1 at a level of 0.4%, at the expense of corn.
[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France

Table 2. Chemical analysis of wheat middlings and dried distillers grains with solubles (DDGS; as-fed basis)[1]

Item	Wheat middlings	DDGS	Soybean meal	Corn
DM, %	89.73[2]	90.34	89.89	88.22
CP, %	15.7(15.9)	22.3(27.2)	44.8(46.5)	9.3(8.50)
ADF, %	10.7	13.0	7.0	3.7
NDF, %	32.0	27.8	10.9	11.7
Crude fiber, %	6.6(7.0)	7.7(7.3)	4.2(3.9)	2.3(2.2)
NFE, %[3]	56.6	43.5	34.2	71.0
Ca, %	0.14(0.12)	0.06(0.03)	0.28(0.03)	0.09(0.03)
P, %	1.08(0.93)	0.85(0.71)	0.79(0.69)	0.37(0.28)
Fat, %	3.8	9.9	1.5	3.3
Ash, %	5.1	4.3	6.6	1.7

[1] Values in parentheses indicate those used in diet formulation.
[2] All values are averages of the two groups.
[3] NFE: nitrogen-free extract.

Table 3. Chemical analysis of diets (as-fed basis)[1]

Diet:[2]	Control			HBP				
Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet
DM, %	89.38[4]	89.51	89.12	90.54	90.38	89.16	90.53	88.95
CP, %	21.5	21.2	21.6	25.8	24.9	25.0	25.7	25.7
ADF, %	3.8	3.6	4.1	8.5	7.8	7.4	7.7	7.9
NDF, %	7.0	7.4	7.3	19.3	18.2	17.4	17.4	17.8
Crude fiber, %	2.0	2.2	2.2	5.2	5.0	4.7	4.7	4.8
NFE, %[5]	57.5	58.4	56.9	47.4	49.2	48.2	47.9	47.1
Ca, %	0.72	0.72	0.61	0.70	0.53	0.57	0.67	0.75
P, %	0.62	0.60	0.61	0.72	0.71	0.68	0.69	0.71
Fat, %	1.9	1.9	1.9	4.6	3.7	3.8	4.3	3.8
Ash, %	5.6	5.2	5.5	6.1	6.4	6.4	6.4	6.2

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Control diet was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
[3] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 μ; soybean meal = 889 μ and 421 μ; DDGS = 701 μ and 377 μ; midds =534 μ and 357 μ, respectively.
[4] All values are averages of the two groups.
[5] NFE: nitrogen-free extract.

Table 4. Chemical analysis

Diet:[1]	Control			HBP				
Ingredient processed:[2]	---	Corn	Corn	---	Corn	Corn	Diet	Diet
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet
Particle size, µ	696[3]	517	---	679	551	---	397	---
Bulk density, lb/bu	55.9	58.4	60.2	42.9	45.4	52.8	45.2	54.4
Angle of repose, °	47.4	53.0	---	48.1	52.3	---	54.9	---
Standard pellet durability index	---	---	93.6	---	---	95.4	---	96.8
Modified pellet durability index	---	---	90.4	---	---	93.7	---	95.7
Fines, %	---	---	1.2	---	---	1.1	---	0.7
Production rate, lb/h	---	---	3194	---	---	2787	---	2781
Hot pellet temperature, °F	---	---	177	---	---	177	---	181

[1] Control diet was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
[2] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 µ; soybean meal = 889 µ and 421 µ; DDGS = 701 µ and 377 µ; midds = 534 µ and 357 µ, respectively.
[3] All values are averages of the two groups.

Table 5. Effects of feeding varying particle sizes and diet forms on 25- to 50-lb nursery pig performance[1]

Treatment:	1	2	3	4	5	6	7	8					
Diet:[2]	Control			HBP						Probability, *P*<			
Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet					
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet	SEM	Diet form[4]	Corn μ[5]	Diet[6]	Grinding[7]
d 0 to 21													
ADG, lb	1.43	1.37	1.36	1.29	1.24	1.32	1.21	1.26	0.05	0.03	0.02	<0.001	0.05
ADFI, lb	2.21	2.12	2.09	2.06	2.02	2.00	1.90	1.96	0.09	0.89	0.08	<0.001	0.02
F/G	1.55	1.55	1.54	1.60	1.63	1.52	1.57	1.56	0.02	0.004	0.32	0.01	0.51
Caloric efficiency[8]													
ME	2323	2331	2307	2360	2409	2247	2320	2298	34.4	0.004	0.33	0.44	0.51
NE	1658	1663	1647	1656	1691	1577	1628	1613	24.7	0.004	0.33	0.38	0.51
Wt, lb													
d 0	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	0.35	0.95	0.99	0.99	0.93
d 21	54.7	53.4	54.4	51.6	51.4	52.5	49.4	51.0	51.3	0.06	0.37	<0.001	0.03

[1] A total of 675 pigs (PIC 1050, initially 24.5 lb BW and 37 d of age) were used in a 21-d growth trial with 5 pigs per pen and 17 pens per treatment.
[2] Control was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings.
[3] Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 μ; soybean meal = 889 μ and 421 μ; DDGS = 701 μ and 377 μ; midds = 534 μ and 357 μ, respectively.
[4] Treatments 2, 5, and 7 vs. 3, 6, and 8.
[5] Treatments 1 and 4 vs. 2 and 5.
[6] Treatments 1, 2, and 3 vs. 4, 5, and 6.
[7] Treatments 5 and 6 vs. 7 and 8.
[8] Caloric efficiency is expressed as kcal/lb gain.

Table 6. Effects of feeding varying particle sizes and diet form on 25- to 50-lb nursery pig performance[1]

Diet:[2]	Control			HBP						Probability, *P*<			
Ingredient processed:[3]	---	Corn	Corn	---	Corn	Corn	Diet	Diet					
Item / Diet form:	Meal	Meal	Pellet	Meal	Meal	Pellet	Meal	Pellet	SEM	Diet form[4]	Corn μ[5]	Diet[6]	Grinding[7]
d 0 to 21													
Feed cost/pig, $	8.68	8.35	8.35	7.20	7.07	7.13	6.70	7.05	0.337	0.19	0.07	<.0001	0.09
Feed cost/lb gain, $[8]	0.29	0.29	0.29	0.27	0.27	0.26	0.26	0.27	0.004	0.24	0.31	<.0001	0.87
Total revenue/pig, $[9,10]	19.59	18.77	19.46	17.59	17.46	18.23	16.16	17.22	0.792	0.01	0.25	<.0001	0.01
IOFC[11]	10.91	10.42	11.11	10.39	10.39	11.11	9.45	10.17	0.494	0.01	0.49	0.52	0.01

1 A total of 675 pigs (PIC 1050, initially 24.5 lb BW and 37 d of age) were used in a 21-d growth trial with 5 pigs per pen and 17 pens per treatment.
2 Control was a corn-soybean meal–based diet; high-by-product diet (HBP) consisted of a corn-soybean meal base with 30% DDGS and 20% wheat middlings.
3 Ingredients were processed separately through a hammer mill using a 1/16-in. screen. Average particle sizes for ingredients before and after grinding were: corn = 620 and 352 μ; soybean meal = 889 μ and 421 μ; DDGS = 701 μ and 377 μ; midds =534 μ and 357 μ, respectively.
4 Treatments 2, 5, and 7 vs. 3, 6, and 8.
5 Treatments 1 and 4 vs. 2 and 5.
6 Treatments 1, 2, and 3 vs. 4, 5, and 6.
7 Treatments 5 and 6 vs. 7 and 8.
8 Feed cost/lb gain = feed cost/lb × F/G, assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton; pelleting $6/ton.
9 One pound of live gain was considered to be worth $0.65.
10 Total revenue/pig = total gain/pig × $0.65.
11 Income over feed cost = total revenue/pig – feed cost/pig.

Effects of Corn Particle Size, Complete Diet Grinding, and Diet Form on Finishing Pig Growth Performance, Caloric Efficiency, Carcass Characteristics, and Economics[1,2]

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Summary

A total of 855 pigs (PIC TR4 × Fast Genetics York × PIC Line 02), initially 56.54 lb BW) were used in a 111-d trial to evaluate the effects of corn particle size, complete diet grinding, and diet form (meal or pellet) on finishing pig growth performance, caloric efficiency, carcass characteristics, and economics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 9 replications per treatment. The same corn-soybean meal–based diets containing 30% dried distillers grains with solubles (DDGS) and 20% wheat middlings (midds) were used for all treatments. Diets were fed in four phases. Different processing techniques were used to create the 5 dietary treatments: (1) roller grinding the corn to approximately 650 µ with the diet fed in meal form; (2) hammer-mill grinding the corn to approximately 320 µ with the diet fed in meal form; (3) Treatment 2 but pelleted; (4) corn initially roller-mill ground to approximately 650 µ, then the complete mixed diet reground through a hammer mill to approximately 360 µ with the diet fed in meal form; and (5) Treatment 4 but pelleted.

Overall (d 0 to 111), reducing corn particle size from approximately 650 to 320 µ improved ($P < 0.03$) F/G, caloric efficiency, feed cost per lb of gain, and income over feed cost (IOFC). Grinding the complete diet decreased ADG, ADFI, and final weight when the diet was fed in meal form, but increased performance when fed in pelleted form resulting in diet form × portion ground interactions ($P < 0.02$). Pelleting the diet improved ($P < 0.001$) ADG, F/G, caloric efficiency on an ME and NE basis, final weight, carcass weight, and IOFC.

For carcass characteristics, feeding a pelleted diet increased ($P < 0.001$) HCW, which led to a diet form × portion ground interaction ($P < 0.02$), meaning HCW decreased when the complete diet was ground and fed in meal form but increased when the same diet was fed in pellet form. Grinding the complete diet decreased ($P < 0.03$) loin depth, and pelleting diets increased ($P < 0.02$) loin depth.

Reducing corn particle size and pelleting complete diets improved performance, carcass characteristics, and economic return. Fine-grinding the entire diet was detrimental

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to performance, carcass characteristics, and economics when fed in meal form but improved performance and economic return when pelleted.

Key words: finishing pig, ingredient processing, particle size, pellet

Introduction

Increased cost of ingredients, specifically for corn and soybean meal, has resulted in producers feeding diets containing higher levels of by-products to finishing pigs. Some of the by-product alternatives lack the energy concentration of basic corn-soybean meal diets. This decrease in energy leads to decreased performance and an increase in time needed for hogs to reach market weight targets. In light of these circumstances, more emphasis is being placed on feed processing technologies to improve utilization of high by-product diets. First, reducing particle size of individual ingredients or whole diets may improve their digestibility and improve feed efficiency, but little research has explored the effects of fine-grinding the complete diets or pelleting high by-product diets on pig performance. Secondly, pelleting high by-product diets will improve diet bulk density, reduce feed wastage, and potentially improve diet digestibility. Adding the necessary infrastructure to pellet diets has a high initial cost and necessitates increased energy usage, which leads to higher feed cost for the producer, but these extra costs may provide more economic return though improved feed efficiency. Thus, the economics associated with the increased production costs of grinding and pelleting also need to be studied.

The objective of this study was to determine the effects of corn particle size (650 or 320 μ), complete diet grinding, and diet form (meal or pellet) on finishing pig growth performance, caloric efficiency, carcass characteristics, and economics.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the New Fashion Pork Research Facility (Round Lake, MN) in a commercial research-finishing barn in northwestern Iowa. The barn was tunnel ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 855 pigs (PIC TR4 × Fast Genetics York-AND × PIC Line 02), initially 56.5 lb BW) were used in a 111-d trial. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 5 dietary treatments with 9 replications per treatment with 19 pigs per pen. Treatment diets were fed in a 4-phase feeding program from d 0 to 35, 35 to 65, d 65 to 93, and d 93 to 111 (Table 1). Within each phase, the same corn-soybean meal–based diet containing 30% DDGS and 20% midds was used for all 5 experimental treatments within each phase. The 5 treatments were achieved by applying different processing techniques to the same diet: (1) roller-milled corn ground to approximately 650 μ with the diet fed in meal form, (2) hammer-milled corn ground to approximately 320 μ with the diet fed in meal form, (3) Treatment 2 but pelleted; (4) Treatment 1 but complete diet reground through a hammer mill to approximately 360 µ with the diet fed in meal form, and (5) Treatment 4 but pelleted. All diets were prepared at New Fashion Pork's feed mill in Estherville, IA.

For caloric efficiency calculations, feed ingredients were assigned an ME value according from the NRC (1998[5]), except DDGS, which was assigned the energy value for corn (1,551 kcal/lb). For NE, values for the growing pig by INRA (2004[6]) were used.

On d 93 of the trial, pens of pigs were weighed and the 3 heaviest pigs (selected by the marketing serviceman) were loaded and transported 350 miles to Triumph Foods in St. Joseph, MO, for harvest. Similarly, on d 100, the next 3 heaviest pigs, as selected by the marketing serviceman, were loaded and transported to Triumph Foods for harvest. The remaining pigs were transported to Triumph Foods on d 111 for harvest. Due to the transportation length and summer temperatures, yield (calculated using live weight at the farm and plant HCW) was lower for all marketing events than typical commercial yields. At the plant, backfat depth and loin depth were measured, and percentage lean was calculated using NPPC (1991) guidelines for lean containing 5% fat: Lean % = (2.83 + (0.469 × (HCW)) – (18.47 × (fat depth)) + (9.824 × loin depth)) / (HCW).

Caloric efficiencies of pens were determined on both an ME and NE (INRA, 2004) basis. Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Lastly, feed cost/pig, feed cost/lb gain, revenue/pig, and IOFC were also calculated. Diet costs were determined with the following ingredient costs: corn = $0.14/lb, soybean meal = $0.24/lb, midds = $0.12/lb, DDGS = $0.14/lb. Processing costs were: grinding = $5/ton, mixing = $3/ton, delivery and handling = $7/ton, and pelleting = $6/ton. Feed cost/pig was determined by total feed intake × feed cost, $/lb. Feed cost/lb gain was calculated using F/G × feed cost, $/lb. Revenue/pig was determined by total gain × $0.65/lb live gain, and IOFC was calculated using revenue/pig – feed cost/pig.

Samples of corn, soybean meal, midds, DDGS, and complete diets were collected and submitted to Ward Laboratories, Inc. (Kearney, NE) for analysis of DM, CP, ADF, NDF, crude fiber, fat, ash, Ca, and P (Table 2). Bulk density and particle size of the corn, soybean meal, wheat middlings, DDGS, and complete diets also were determined along with angle of repose for all ingredients and diets in meal form. For all diets in pelleted form, pellet durability index (PDI) and percentage fines (Table 3) were determined.

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Data were analyzed to determine any diet form × portion ground interactions. Main effects of corn particle size (Treatment 1 vs. 2), grinding (diets 2, 3 vs. 4, 5) and diet form (diets 2, 4 vs. 3, 5) were determined. Results were considered significant at $P \le 0.05$ and considered a trend at $P \le 0.10$.

[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez, and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Results and Discussion

The chemical analysis of the midds, DDGS, corn, and soybean meal (Table 2) indicated that most nutrients were similar to formulated values. Crude protein levels were slightly higher for corn and DDGS and slightly lower for midds than calculated values. Crude fiber was slightly lower for midds and DDGS and slightly higher for corn and soybean meal, and Ca and P levels were slightly higher for all ingredients than formulated values (Table 3). Lastly, fat values were higher for DDGS and slightly lower for midds, corn, and soybean meal than formulated values. Bulk density was similar between all meal diets (Table 4). As expected, pelleting increased the bulk density of the diets. As a greater proportion of the diet was finely ground, particle size decreased and angle of repose increased, which indicates a poorer flowing diet. Pellet durability indexes were similar between pelleted diets, but fine-grinding the complete diet slightly decreased percentage fines in the pelleted diets.

For the overall experiment (d 0 to 111), reducing particle size of the corn from 650 to 320 µ did not affect ADG or ADFI but improved ($P < 0.003$) F/G, caloric efficiency, feed cost/lb of gain, and IOFC (Table 5). Every 100-µ reduction in particle size improved F/G by approximately 1%.

Diet form × portion ground interactions were observed ($P < 0.02$) for ADG, ADFI, final weight, market weight per pig placed, percentage removals per pen, and HCW. These interactions occurred because finely grinding the complete diet reduced each variable when fed in meal form, whereas pigs fed that same diet in pellet form had increased responses for each of the measurements. The increased removals per pen for the finely ground complete diet that was pelleted were noticeable; however, no clear link was found between removals and feed processing in this study. The decrease in market weight per pig placed interaction is due to Treatment 5 having the lowest value, which was a cause of the high removal rate for the treatment. More research needs to be conducted to evaluate whether this effect was specifically diet-related.

Pelleting the diet improved ($P < 0.001$) ADG, F/G, caloric efficiency, final weight, HCW, and loin depth and tended to increase ($P < 0.07$) BF. Pelleting also reduced ($P < 0.002$) feed cost/lb of gain and increased ($P < 0.001$) IOFC. Grinding the complete diet increased ($P < 0.01$) feed cost/lb of gain and reduced ($P < 0.03$) IOFC and loin depth.

These data suggest that performance can be improved through a variety of feed-processing technologies. Fine-grinding corn and pelleting the diet improved efficiency of gain and economic return in finishing pigs. The response to corn particle size is particularly significant, because the diets used in the study included only 30 to 39% corn due to the inclusion of DDGS and midds; however, fine-grinding the entire diet and feeding in meal form reduced feed intake. We speculate this was caused by reduced palatability. Interestingly, when this diet was pelleted, feed intake improved, resulting in the highest numerical growth rate of any treatment. Disappointingly, feed efficiency and caloric efficiency were identical in pelleted diets regardless of whether only the corn was finely ground or if the complete diet was finely ground. This result indicates that fine-grinding DDGS, wheat midds, and soybean meal did not improve their energy value. Although we observed increased incidence of removals for the reground and pelleted diet treatment, more work should be done to determine if the removals are truly an effect of the processing technologies.

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

	Phase			
Item	1	2	3	4
Ingredient, %				
Corn	30.94	34.82	39.03	32.69
Soybean meal (46.5% CP)	16.81	12.98	8.77	15.09
Wheat middlings	20.00	20.00	20.00	20.00
Dried distillers grains with solubles	30.00	30.00	30.00	30.00
Limestone	1.50	1.50	1.50	1.50
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10
L-lysine HCl	0.30	0.25	0.25	0.25
Ractopamine HCL, 9g/lb[2]	---	---	---	0.03
Total				
	100	100	100	100
Standard ileal digestible (SID) amino acids, %				
Lysine	0.98	0.85	0.75	0.90
Isoleucine:lysine	70	74	75	73
Methionine:lysine	32	34	36	34
Met & Cys:lysine	63	68	73	67
Threonine:lysine	63	67	69	66
Tryptophan:lysine	19	19	19	19
Valine:lysine	73	80	86	78
Total lysine, %	1.16	1.02	0.91	1.07
ME, kcal/lb[3]	1,468	1,472	1,477	1,469
NE, kcal/lb[4]	697	708	720	701
SID lysine:ME, g/Mcal	3.03	2.62	2.30	2.78
CP, %	21.2	19.7	18.1	20.5
Crude fiber, %	4.6	4.5	4.4	4.5
NDF, %	6.7	6.7	6.8	6.7
ADF, %	3.0	3.0	2.9	3.0
Ca, %	0.67	0.66	0.64	0.66
P, %	0.60	0.59	0.57	0.59
Available P, %	0.42	0.41	0.41	0.41

[1] Phase 1 diets were fed from d 0 to 35, Phase 2 from d 35 to 65, Phase 3 from d 65 to 93, and Phase 4 from d 93 to 111.
[2] Paylean; Elanco Animal Health (Greenfield, IN).
[3] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.
[4] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Table 2. Chemical analysis of ingredients (as-fed basis)[1]

Item	Wheat middlings	DDGS[2]	Corn	Soybean meal
DM, %	90.76	90.63	87.73	91.14
CP, %	16.3(15.9)	27.0(27.2)	6.8(8.5)	46.5(46.5)
ADF, %	11.0	13.5	2.4	6.1
NDF, %	31.2	27.1	7.8	6.7
Crude fiber, %	7.6(7.0)	8.7(7.3)	1.8(2.2)	2.9(3.9)
NFE, %[3]	56.4	37.2	75.0	32.7
Ca, %	0.14(0.12)	0.06(0.03)	0.06(0.03)	0.37(0.34)
P, %	1.19(0.93)	0.89(0.71)	0.29(0.28)	0.71(0.69)
Fat, %	3.7(4.2)	11.4(10.7)	2.99(3.9)	1.1(1.5)
Ash, %	5.47	4.28	1.09	5.94
Particle size, µ	627	580	647; 322[4]	1,070
Bulk density, lb/bu	28.05	45.74	50.59; 48.18[5]	61.68

[1] Values in parentheses indicate those used in diet formulation.
[2] DDGS: dried distillers grains with solubles.
[3] NFE: nitrogen-free extract.
[4] Average roller-milled corn was 647 µ; average hammer-milled corn was 322 µ.
[5] Average roller-milled corn was 50.6 lb/bu; average hammer-milled corn was 48.2 lb/bu.

Table 3. Chemical analysis of diets (as-fed basis)[1]

Item[2]	Phase 1	Phase 2	Phase 3	Phase 4
DM, %	89.87	89.48	89.61	89.89
CP, %	20.6	19.3	18.4	20.6
ADF, %	7.1	7.3	7.1	7.2
NDF, %	15.9	16.3	15.8	26.8
Crude fiber, %	4.4	4.5	4.4	4.8
NFE, %[3]	53.5	54.3	55.6	52.5
Ca, %	0.48	0.66	0.38	0.39
P, %	0.61	0.63	0.57	0.67
Fat, %	4.7	4.9	4.9	5.5
Ash, %	5.45	5.23	5.01	5.61

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] Diet 1 was used for analysis, because all treatments were formulated identically.
[3] NFE: nitrogen-free extract.

Table 4. Analysis of diets[1]

Item	Portion ground:[2] / Diet form:	---[3]	Corn		Complete diet	
		Meal	Meal	Pellet	Meal	Pellet
Bulk density, lb/bu						
Phase 1		45.5	44.9	61.3	46.6	62.2
Phase 2		44.6	44.3	59.7	44.2	61.4
Phase 3		44.3	44.9	61.0	44.6	62.4
Phase 4		45.1	44.8	61.7	44.9	62.3
Particle size, µ						
Phase 1		552	515	---	394	---
Phase 2		619	483	---	344	---
Phase 3		612	440	---	365	---
Phase 4		602	511	---	355	---
Angle of repose, °						
Phase 1		51.8	52.8	---	58.6	---
Phase 2		54.4	53.1	---	58.8	---
Phase 3		52.3	57.1	---	58.4	---
Phase 4		52.1	55.5	---	59.1	---
Standard pellet durability index						
Phase 1		---	---	96.1	---	96.3
Phase 2		---	---	94.4	---	96.7
Phase 3		---	---	92.9	---	93.0
Phase 4		---	---	94.5	---	97.2
Modified pellet durability index						
Phase 1		---	---	93.2	---	91.5
Phase 2		---	---	91.7	---	95.0
Phase 3		---	---	88.1	---	90.0
Phase 4		---	---	90.9	---	92.9
Fines, %						
Phase 1		---	---	14.1	---	11.3
Phase 2		---	---	31.7	---	15.7
Phase 3		---	---	8.1	---	7.8
Phase 4		---	---	13.8	---	14.6

[1] A composite sample of four subsamples was used for analysis.
[2] Ingredients or complete diets were ground through a hammer mill using a 1/16-in. screen. Corn was ground to an approximate particle size of 320 µ; complete diets were ground to approximately 360 µ.
[3] Corn for the first treatment was ground through a roller mill and was approximately 650 µ.

Table 5. The effect of grinding corn or a complete diet and diet form (meal vs. pellet) on finishing pig performance[1]

	Treatments:	1	2	3	4	5		Probability, P<			
	Portion ground:[2]	---[3]	Corn		Complete diet						
Item	Diet form:	Meal	Meal	Pellet	Meal	Pellet	SEM	Corn µ[4]	Diet form × portion ground	Grinding[5]	Diet form[6]
d 0 to 111											
ADG, lb		2.02	2.06	2.11	1.99	2.17	0.018	0.15	0.001	0.89	0.0001
ADFI, lb		5.70	5.57	5.47	5.46	5.63	0.058	0.13	0.02	0.68	0.52
F/G		2.82	2.71	2.60	2.74	2.60	0.035	0.003	0.58	0.50	0.0001
Caloric efficiency[7]											
ME		4,153	3,991	3,824	4,034	3,828	37.0	0.003	0.59	0.50	0.0001
NE		1,998	1,920	1,840	1,941	1,841	17.9	0.003	0.56	0.51	0.0001
BW, lb											
d 0		56.5	56.6	56.6	56.5	56.6	0.83	0.93	0.96	0.99	0.98
d 111		270.7	275.6	276.8	268.5	285.3	2.44	0.15	0.002	0.76	0.001
Market wt per pig placed, lb		254.4	252.8	269.7	262.7	250.4	7.50	0.88	0.04	0.51	0.75
Removal/pen, %		6.6	8.8	4.1	2.3	12.9	2.69	0.56	0.005	0.65	0.26

continued

Table 5. The effect of grinding corn or a complete diet and diet form (meal vs. pellet) on finishing pig performance[1]

Treatments:	1	2	3	4	5		Probability, *P*<			
Portion ground:[2]	---[3]	Corn		Complete diet						
Item / Diet form:	Meal	Meal	Pellet	Meal	Pellet	SEM	Corn μ[4]	Diet form × portion ground	Grinding[5]	Diet form[6]
Carcass characterisitcs[8,9,10]										
HCW, lb	200.4	201.1	205.2	196.9	208.7	1.643	0.74	0.02	0.82	<.0001
Yield, %	73.6	72.6	73.0	73.2	72.7	0.347	0.06	0.21	0.72	0.83
Backfat, mm	19.2	19.5	19.7	19.3	20.5	0.342	0.52	0.10	0.36	0.07
Loin depth, mm	60.1	59.5	61.5	59.4	60.2	0.539	0.35	0.25	0.13	0.02
Lean, %[11]	52.9	52.7	53.0	52.8	52.5	0.169	0.35	0.07	0.15	0.91
Economics										
Feed cost/pig, $	99.23	97.35	96.87	96.48	102.19	1.007	0.18	0.002	0.02	0.01
Feed cost/lb gain, $[12]	0.44	0.43	0.41	0.44	0.43	0.004	0.004	0.87	0.01	0.002
Total revenue/pig, $[13,14]	152.50	155.29	159.07	150.44	163.54	1.373	0.15	0.001	0.89	<.0001
IOFC[15]	53.27	57.94	62.20	53.96	61.35	1.143	0.01	0.15	0.03	<.0001

[1] A total of 855 pigs (PIC TR4 × (Fast Genetics York-AND x PIC Line 02) , initially 56.54 lb BW) were used in a 111-d trial, with 19 pigs per pen and 9 pens per treatment.
[2] Ingredients or complete diets were ground through a hammer mill using a 1/16-in. screen. Corn was ground to approximate particle size of 320μ; complete diets were ground to approximately 360 μ.
[3] Corn was ground through a roller mill and was approximately 650 μ.
[4] Treatment 1 vs. 2.
[5] Treatments 2, 3 vs. 4, 5.
[6] Treatments 2, 4 vs. 3, 5.
[7] Caloric efficiency is expressed as kcal/lb of gain.
[8] The three largest pigs were marketed from each pen on d 93.
[9] The three largest pigs were marketed from each pen on d 100.
[10] All remaining pigs were marketed from each pen on d 111.
[11] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83 + (0.469 × (HCW)) – (18.47 × (fat depth)) + (9.824 × loin depth)) / (HCW).
[12] Feed cost/lb gain = (feed cost/pig)/total gain. Costs were grinding = $5/ton, mixing = $3/ton, delivery and handling = $7/ton, pelleting = $6/ton.
[13] One lb of body gain = $0.68/lb.
[14] Total revenue/pig = total gain/pig × $0.68.
[15] Income over feed cost = total revenue/pig – feed cost/pig.

The Effects of MicroSource S on Growth Performance, Fecal Consistency, and Postcleaning Microbial Load of Growing-Finishing Pigs[1]

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Summary

A total of 1,245 pigs (PIC 1050 × 337, initially 106 lb) were used in a 90-d study to determine the effects of MicroSource S (DSM Nutritional Products Inc., Parsippany, NJ) and diet type on growth performance, carcass traits, fecal consistency, pen cleaning time, and postcleaning microbial load in growing-finishing pigs raised under commercial conditions. Pens of pigs were balanced by initial weight and randomly allotted to 1 of 6 dietary treatments in a completely randomized design with 25 to 26 pigs per pen and 8 replications per treatment. Treatments were arranged as a 3 × 2 factorial with main effects of MicroSource S (0, 1×, or 1.3×) and diet type (corn-soybean meal or a by-product–based diet with 30% dried distillers grains with solubles [DDGS] and 15% bakery by-product). The MicroSource S dose in the diet was 147 million cfu/g feed for the 1× level and 191 million cfu/g feed for the 1.3× level. Fecal consistency and manure buildup in each pen was scored at the end of the trial by 3 observers with the average value per pen used for analysis. Time required to wash each individual pen was also recorded. After pens were cleaned and dried, ATP (adenosine triphosphate) testing was used to measure microbial load in each pen.

Overall (d 0 to 90), increasing MicroSource S had no effect ($P > 0.12$) on growth performance, carcass characteristics, ATP concentration, manure score, or wash time, but pigs fed 1× MicroSource S tended (quadratic, $P = 0.07$) to have the lowest carcass yield. No interactions ($P > 0.33$) were observed between MicroSource S dosage and diet type for growth performance, ATP concentration, manure score, or wash time; however, a MicroSource S × diet type interaction (quadratic, $P < 0.01$) was observed for loin depth. In pigs fed the 1× MicroSource S diet, loin depth increased when fed the by-product diet, but MicroSource S reduced loin depth in pigs fed either the corn-soybean meal or 1.3× diets. No differences occurred in ADG among pigs fed the corn-soybean meal-based diet and those fed the by-product diet. Pigs fed the by-product diet had greater ($P < 0.01$) ADFI and poorer ($P < 0.01$) F/G compared with those fed the corn-soybean meal diet. Pens of pigs fed the by-product diets required more ($P < 0.01$) time to wash, which appeared to be the result of an increase ($P = 0.08$) in manure buildup. In this trial, the 1× or 1.3× level of MicroSource S did not improve growth performance or alter fecal consistency, postcleaning microbial load, or barn wash time.

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Key words: by-products, enzyme fecal consistency, microbial load, finishing pigs, wash time

Introduction

Probiotic bacteria have been promoted to improve growth performance and as an alternative method of preventing gastrointestinal disease in several species. Supplemental feeding of *Bacillus spp.* bacteria also has been hypothesized to alter fecal consistency due to the reduction in diarrhea incidence by its action in prevention of pathogenic bacteria at the binding site. A previous study at Kansas State University (Nitikanchana et al., 2011[4]) was conducted with increasing dietary addition of *Bacillus spp.* (0, 1×, or 10×; Sporzyme, Direct Biologicals Inc., Crofton, NE) in corn-soybean meal and by-product (DDGS and bakery meal)–based diets. Although no differences were observed in growth performance, barn wash time decreased approximately 50 sec per pen when pigs were fed the 10× *Bacillus* diet.

This experiment investigated the effect of another *Bacillus* product, MicroSource S, on growth performance and carcass composition of finishing pigs fed corn-soybean meal or by-product diets and its effects on fecal consistency, pen wash time, and postcleaning microbial load after barn closeout.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were provided through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of measuring feed amounts for individual pens.

A total of 1,245 pigs (PIC 1050 × 337, initially 106 lb BW) were used in a 90-d study. A similar number of barrows and gilts were placed in each pen, with 25 to 26 pigs per pen and 8 pens per treatment. Pens of pigs were allotted to 1 of 6 treatments in a completely randomized design while balancing for weight. Treatments were arranged in a 3 × 2 factorial with main effects of MicroSource S dose (0, 1×, or 1.3×) and diet type (corn-soybean meal or DDGS/bakery–based diets). The added MicroSource S dose was 147 million cfu/g feed for the 1× level and 191 million cfu/g feed for the 1.3× dose. The by-product diets contained 30% DDGS and 15% bakery by-product. From d 72 to 90, DDGS level was lowered to 20% and diets in this phase also contained 9 g/ton of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN). Diets were fed in 5 phases, from 106 to 125 lb, 125 to 160 lb, 160 to 200 lb, 200 to 245 lb, and 245 lb to market (Tables 1 and 2).

Pens of pigs were weighed and feed disappearance was recorded at d 9, 26, 48, 72, and 90 to determine ADG, ADFI, and F/G. At the end of the experiment, pigs were individually tattooed by pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Pigs were transported to JBS Swift and Company (Worthing-

[4] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 240–246.

ton, MN) for processing. Standard carcass criteria of loin and backfat depth, HCW, percentage lean, and percentage carcass yield were collected.

To measure fecal consistency, 3 people scored each pen for manure texture and buildup at the end of the trial. The scores were averaged to determine a mean score, which was used for analysis. Manure textures were categorized as firm, medium, and loose with scores of 1, 0, and -1, respectively. Manure buildup was categorized as 1 for visual manure buildup and -1 for no visual manure buildup. The time required to wash each individual pen was recorded to determine wash time.

To measure the microbial load, ATP testing was used after the barn was washed and dried. A 100 cm^2 surface area in front of the feeder and in the opposite corner facing the alley way in each pen was swabbed (PocketSwab Plus ATP Swab, Charm Sciences Inc., Lawrence, MA) and immediately tested for the presence of ATP using a luminometer.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Treatments were arranged in a 2 × 3 factorial and data were analyzed for the main effects of diet type, linear and quadratic effect of MicroSource S, and any interactions between linear and quadratic effects of MicroSource S and diet type. Contrast coefficients for MicroSource S (0, 1×, and 1.3×) were determined for unequally spaced treatments by using the IML procedure of SAS. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. Pen was the experimental unit for all data analysis, and significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

Results and Discussion

For the overall period, no linear or quadratic interactions ($P > 0.33$; Table 3) were observed between increasing MicroSource S dosage and diet type on finishing pig growth performance. For carcass characteristics, loin depth in pigs fed the 1× *Bacillus* in the by-product diet was greater than in that of pigs fed the corn-soybean meal diet, but in the control or 1.3× dosage, loin depth decreased, resulting in a MicroSource S and diet type interaction (quadratic, $P < 0.01$). No interactions were detected ($P > 0.32$) in ATP concentration, manure score, or wash time.

For the main effect of Microsurce S dosage, no differences were observed ($P > 0.12$; Table 4) in growth performance for pigs fed increasing MicroSource S for the overall period (d 0 to 90). MicroSource S dosage did not influence carcass characteristics ($P > 0.14$), but carcass yield tended to decrease quadratically ($P = 0.07$); pigs fed 1× *Bacillus* had a lower yield than those fed the control or 1.3× *Bacillus*. Concentration of ATP, manure score, and wash time were not altered ($P > 0.13$) by MicroSource S dosage.

For diet type, pigs fed the by-product diet had greater ($P < 0.01$; Table 5) ADFI than pigs fed the corn-soybean meal diet; however, with no differences in ADG ($P = 0.30$), feed efficiency was poorer ($P < 0.01$) for pigs fed the by-product diets. Carcass characteristics did not differ between diet types, but HCW of pigs fed the corn-soybean meal diet tended to be greater ($P = 0.06$) than those fed with the by-product diet. No differences were detected ($P > 0.27$) in ATP concentration between the diet type. More manure buildup was observed ($P < 0.01$) in pens where pigs were fed by-product diets compared with pens of pigs fed corn-soybean meal diets, but manure texture was not different ($P = 0.85$) between diet types. As a result of more manure buildup, pens where by-product diets were fed required longer wash time ($P < 0.01$) than pens of pigs fed corn-soybean meal diets. Wash time was 2.7 min longer per pen where pigs were fed the by-product diets than pens fed with corn-soybean meal diets. When extrapolated over a 48-pen barn, feeding the by-product diets would increase wash time per barn by approximately 2 h (2 h and 10 min) compared with a barn where corn-soybean meal diets were fed.

In this study, increasing MicroSource S to 191 million cfu/g of feed did not improve growth performance or carcass characteristics. This result is similar to those of Nitikanchana et al. (2011[5]), who observed no improvement with increasing a different *Bacillus* enzyme to 2 billion cfu/g of feed. In that trial, pigs fed the *Bacillus* product had firmer stools, resulting in a numeric decrease in pen wash time by 50 sec per pen for pigs fed 2 billion cfu/g of feed compared with the control. The present study did not observe the difference in manure score or wash time, which may be due to the dosage of *Bacillus* with an addition of only 191 million cfu/g of feed.

The response in diet types replicated the results of Nitikanchana et al. (2011), where pigs fed with by-product diet had poorer feed efficiency due to the higher feed intake than pigs fed with corn-soybean meal diet. Also, feeding pigs the by-product diet increased manure buildup and resulted in a longer barn wash time by approximately 2 h in both trials.

MicroSource S did not affect growth performance of growing-finishing pigs or alter fecal consistency, postcleaning microbial load, or barn wash time at the 1× or 1.3× level of dietary inclusion.

[5] Nitikanchana et al., Swine Day 2011, Report of Progress 1056, pp. 240–246.

Table 1. Diet composition[1]

	Phase 1		Phase 2		Phase 3	
Item	Corn-soy	DDGS[2]/ bakery	Corn-soy	DDGS/ bakery	Corn-soy	DDGS/ bakery
Ingredient, %						
Corn	73.05	34.75	76.90	38.60	80.05	41.55
Soybean meal, 46.5% CP	24.35	18.00	20.65	14.20	17.70	11.20
Bakery by-product	---	15.00	---	15.00	---	15.00
DDGS	---	30.00	---	30.00	---	30.00
Monocalcium P, 21% P	0.60	---	0.53	---	0.45	---
Limestone	1.07	1.29	1.04	1.27	1.01	1.26
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
L-threonine	0.04	---	0.02	---	0.015	---
L-lysine sulfate	0.38	0.52	0.34	0.49	0.31	0.46
DL-methionine	0.03	---	0.01	---	---	---
Phytase[3]	0.005	0.005	0.005	0.005	0.005	0.005
MicroSource S[4]	---	---	---	---	---	---
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	1.00	1.00	0.89	0.89	0.80	0.80
Isoleucine:lysine	65	71	66	73	67	75
Leucine:lysine	146	181	155	193	163	206
Methionine:lysine	28	33	28	35	29	37
Met & Cys:lysine	56	62	58	65	59	69
Threonine:lysine	60	64	60	66	61	68
Tryptophan:lysine	18	18	18	18	18	18
Valine:lysine	74	84	76	88	78	91
Total lysine, %	1.12	1.14	1.00	1.05	0.90	0.95
ME, kcal/lb	1,516	1,504	1,517	1,505	1,519	1,505
SID lysine:ME, g/Mcal	2.99	3.02	2.66	2.68	2.39	2.41
CP, %	17.9	21.5	16.4	20.0	15.3	18.9
Ca, %	0.62	0.59	0.58	0.57	0.55	0.56
P, %	0.50	0.47	0.47	0.46	0.44	0.45
Available P, %	0.26	0.28	0.24	0.28	0.22	0.27

[1] Phase 1 diet was fed from 106 to 125 lb, Phase 2 was fed from 125 to 160 lb, and Phase 3 was fed from 160 to 200 lb.
[2] DDGS: dried distillers grains with solubles.
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided an available P release of 0.07%.
[4] MicroSource S, DSM Nutritional Products Inc. (Parsippany, NJ) was added to the diet in place of corn to provide 147 million cfu/g feed for the 1× level and 191 cfu/g feed for the 1.3× dosage.

Table 2. Diet composition[1]

	Phase 4		Phase 5	
Item	Corn-soy	DDGS[2]/ bakery	Corn-soy	DDGS/ bakery
Ingredient, %				
Corn	82.50	44.00	75.95	45.70
Soybean meal, 46.5% CP	15.30	8.85	21.65	17.10
Bakery by-product	---	15.00	---	15.00
DDGS	---	30.00	---	20.00
Monocalcium P, 21% P	0.41	---	0.40	---
Limestone	0.99	1.24	1.00	1.15
Salt	0.35	0.35	0.35	0.35
Vitamin-trace mineral premix	0.10	0.10	0.10	0.10
L-threonine	0.015	---	0.08	0.03
L-lysine sulfate	0.29	0.44	0.35	0.46
DL-methionine	0.01	---	0.05	---
Phytase[3]	0.005	0.005	0.005	0.005
Ractopamine HCl, 9 g/lb[4]	---	---	0.05	0.05
MicroSource S[5]	---	---	---	---
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lysine	0.73	0.73	0.92	0.92
Isoleucine:lysine	68	76	66	70
Leucine:lysine	171	219	152	176
Methionine:lysine	30	40	32	32
Met & Cys:lysine	62	73	60	61
Threonine:lysine	63	70	66	66
Tryptophan:lysine	18	18	18	18
Valine:lysine	80	95	75	83
Total lysine, %	0.82	0.88	1.03	1.07
ME, kcal/lb	1,521	1,506	1,519	1,506
SID Lysine:ME, g/Mcal	2.18	2.20	2.75	2.77
CP, %	14.4	18.0	16.9	19.3
Ca, %	0.53	0.54	0.56	0.53
P, %	0.42	0.44	0.45	0.43
Available P, %	0.21	0.27	0.22	0.23

[1] Phase 4 diet was fed from 200 to 245 lb and Phase 5 diet was fed from 245 lb to market.
[2] DDGS: dried distillers grains with solubles.
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN) provided an available P release of 0.07%.
[4] Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN) was added at 9.0 g/ton.
[5] MicroSource S, DSM Nutritional Products Inc. (Parsippany, NJ) was added to the diet in place of corn to provide 147 million cfu/g feed for the 1× and 191 cfu/g feed for the 1.3× dosage, respectively.

Table 3. Interactive effects of MicroSource S on growth performance, fecal consistency, and postcleaning microbial load (ATP) of growing-finishing pigs[1]

	No MicroSource S		1× MicroSource S[2]		1.3× MicroSource S			Probability, $P<$	
								MicroSource S × diet type	
Diet type[3]	Corn-SBM	By-product	Corn-SBM	By-product	Corn-SBM	By-product	SEM	Linear	Quadratic
d 0 to 90									
ADG, lb	1.98	1.96	1.96	1.93	1.95	1.95	0.017	0.79	0.44
ADFI, lb	5.45	5.81	5.47	5.65	5.42	5.72	0.073	0.47	0.35
F/G	2.76	2.96	2.79	2.92	2.79	2.94	0.032	0.33	0.62
Initial wt, lb	106.0	106.0	106.0	106.0	106.0	106.0	1.996	0.99	1.00
Final wt, lb	282.3	280.0	279.2	276.8	279.1	278.8	2.556	0.76	0.72
Carcass measurements									
HCW, lb	208.6	204.6	204.6	203.0	207.7	203.4	2.053	0.89	0.47
Carcass yield, %	76.5	76.3	75.4	75.0	76.2	76.8	0.781	0.71	0.61
Backfat depth, in.	0.58	0.58	0.61	0.59	0.59	0.57	0.013	0.64	0.55
Loin depth, in.	2.73	2.70	2.68	2.74	2.74	2.66	0.023	0.99	<0.01
Lean, %	58.2	58.2	57.6	58.2	58.2	58.1	0.237	0.78	0.12

continued

Table 3. Interactive effects of MicroSource S on growth performance, fecal consistency, and postcleaning microbial load (ATP) of growing-finishing pigs[1]

	No MicroSource S		1× MicroSource S[2]		1.3× MicroSource S			Probability, *P*< MicroSource S × diet type	
Diet type[3]	Corn-SBM	By-product	Corn-SBM	By-product	Corn-SBM	By-product	SEM	Linear	Quadratic
ATP concentration[4]									
Feeder	284,838	264,510	334,409	336,063	274,021	341,587	47,570	0.43	0.60
Corner	340,825	297,972	388,876	329,010	356,297	279,033	52,311	0.76	0.92
Average	312,831	281,241	361,643	332,537	315,159	310,310	37,415	0.77	0.79
Manure score									
Texture[5]	0.25	0.00	0.13	0.25	0.08	0.13	0.178	0.32	0.64
Buildup[6]	-0.50	0.67	-0.83	0.67	-0.33	0.92	0.235	0.71	0.53
Wash time, min/pen	6.3	8.7	6.1	8.2	6.3	9.7	0.658	0.58	0.40

[1]A total of 1,245 finishing pigs (initial BW 106 lb) were used in a 90-d trial. Pigs were randomly allotted to 1 of 6 dietary treatments with 25 or 26 pigs/pen and 8 pens per treatment. ATP: adenosine triphosphate.

[2] MicroSource S (DSM Nutritional Products Inc., Parsippany, NJ) provided approximately 147 million cfu/g feed for the 1× and 191 million cfu/g feed for the 1.3× dosage, respectively.

[3] By-product diets contained 30% dried distillers grains with solubles (DDGS) and 15% bakery by-product; DDGS was lowered to 20% in the last phase diets.

[4] ATP testing was used to measure ATP concentration as an indicator of microbial load after barn was washed and dried. Floor was swabbed in front of the feeder and in the opposite corner facing the alleyway.

[5] Manure textures were categorized as firm, medium, or loose with scores of 1, 0, and -1, respectively.

[6] Manure buildup was given value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 4. Main effects of MicroSource S on growth performance, fecal consistency, and postcleaning microbial load (ATP) in growing-finishing pigs[1]

	MicroSource S[2]				Probability, *P*<	
	None	1×	1.3×	SEM	Linear	Quadratic
d 0 to 90						
ADG, lb	1.97	1.95	1.95	0.012	0.12	0.81
ADFI, lb	5.63	5.56	5.57	0.052	0.33	0.73
F/G	2.86	2.86	2.86	0.023	0.93	0.86
Initial wt, lb	106.0	106.0	106.0	1.411	1.00	1.00
Final wt, lb	281.1	278.0	279.0	1.808	0.28	0.53
Carcass measurements						
HCW, lb	206.6	203.8	205.6	1.452	0.62	0.21
Carcass yield, %	76.4	75.2	76.5	0.541	0.97	0.07
Backfat depth, in.	0.58	0.60	0.58	0.009	0.56	0.14
Loin depth, in.	2.71	2.71	2.70	0.016	0.58	0.81
Lean, %	58.2	57.9	58.1	0.164	0.54	0.20
ATP concentration[3]						
Feeder	274,674	335,236	307,804	33,637	0.33	0.42
Corner	319,398	358,943	317,665	36,989	0.82	0.39
Average	297,036	347,090	312,735	26,456	0.44	0.27
Manure score						
Texture[4]	0.13	0.19	0.10	0.126	0.98	0.63
Buildup[5]	0.08	-0.08	0.29	0.166	0.65	0.13
Wash time, min/pen	7.5	7.1	8.0	0.465	0.73	0.21

[1] A total of 1,245 finishing pigs (initial BW 106 lb) were used in a 90-d trial. Pigs were randomly allotted to 1 of 6 dietary treatments with 25 or 26 pigs/pen and 8 pens per treatment. ATP: adenosine triphosphate.

[2] The *Bacillus* that was used for this trial was approximately 147 million cfu/g feed for the 1× level and 191million cfu/g feed for the 1.3× level.

[3] ATP testing was used to measure ATP concentration as an indicator of microbial load after barn was washed and dried. Floor was swabbed in front of the feeder and in the opposite corner facing the alleyway.

[4] Manure textures were categorized as firm, medium, or loose with scores of 1, 0, and -1, respectively.

[5] Manure buildup was given the value of 1 for visual manure buildup and -1 for no visual manure buildup.

Table 5. Main effect of diet type on growth performance, fecal consistency, and postcleaning microbial load in growing-finishing pigs[1]

	Diet type			
	Corn-soybean meal	By-product[2]	SEM	Probability, *P*<
d 0 to 90				
ADG, lb	1.96	1.95	0.010	0.30
ADF, lb	5.45	5.73	0.042	<0.01
F/G	2.78	2.94	0.019	<0.01
Initial wt, lb	106.0	106.0	1.52	0.99
Final wt, lb	280.2	278.5	1.476	0.43
Carcass measurements				
HCW, lb	207.0	203.7	1.186	0.06
Carcass yield, %	76.0	76.0	0.448	0.96
Backfat depth, in.	0.59	0.58	0.007	0.18
Loin depth, in.	2.72	2.70	0.013	0.37
Lean, %	58.0	58.1	0.136	0.35
ATP concentration[3]				
Feeder	297,756	314,053	27,465	0.68
Corner	361,999	302,005	30,202	0.17
Average	329,878	308,029	21,602	0.48
Manure score				
Texture[4]	0.15	0.13	0.103	0.85
Buildup[5]	-0.56	0.75	0.136	<0.01
Wash time, min/pen	6.2	8.9	0.380	<0.01

[1]A total of 1,245 finishing pigs (initial BW 106 lb) were used in a 90-d trial. Pigs were randomly allotted to 1 of 6 dietary treatments with 25 or 26 pigs/pen and 8 pens per treatment.
[2] By-product diets contained 30% DDGS and 15% bakery; dried distillers grains with solubles (DDGS) were lowered to 20% in the last phase diets.
[3] ATP (adenosine triphosphate) testing was used to measure ATP concentration as an indicator of microbial load after barn was washed and dried. Floor was swabbed in front of the feeder and in the opposite corner facing the alleyway.
[4] Manure textures were categorized in as firm, medium, or loose with scores of 1, 0, and -1, respectively.
[5] Manure buildup was given the value of 1 for visual manure buildup and -1 for no visual manure buildup.

Effects of Xylanase in High-Co-Product Diets on Nutrient Digestibility in Finishing Pigs[1]

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Summary

A total of 36 pigs (PIC 337 × 1050; initially 185 lb BW) were used in a 14-d study to evaluate the effects of xylanase (Porzyme 9302; Danisco Animal Nutrition, St. Louis, MO) in growing-finishing diets varying in dietary fiber on nutrient digestibility. Pigs were randomly allotted to 1 of 6 dietary treatments in a 2 × 3 factorial. Main effects were increasing dried distillers grains with solubles (DDGS; 35, 42.5, and 50%) with or without xylanase (0 or 4,000 units xylanase per kilogram of diet. The 6 treatment diets were corn-soybean meal–based with 15% added wheat middlings (midds), with 6 replications per treatment. All diets were fed in meal form. Multiple enzyme × DDGS interactive effects ($P < 0.05$) were observed for digestibility of various nutrients. The majority of these interactions resulted from differences in response to increasing DDGS with and without xylanase. In diets with xylanase, apparent digestibility generally decreased as DDGS increased. In diets without xylanase, apparent digestibility decreased as DDGS increased from 35 to 42.5% but increased in diets containing 50% DDGS. Overall, despite the interactions, increasing DDGS regardless of enzyme inclusion lowered (quadratic, $P < 0.01$) apparent fecal digestibility of DM, GE, ADF, NDF, and zinc as well as fecal digestibility (linear, $P < 0.02$) of fat, Ca, and P. Despite the interactions, adding dietary xylanase did not improve digestibility in corn-soybean meal–based diets containing fibrous co-products.

Key words: DDGS, digestibility, enzyme, fiber, finishing pig

Introduction

Feed ingredients such as wheat midds and DDGS are often used as alternatives to corn and soybean meal in swine diets. The majority of the starch is removed from the kernel of DDGS and midds during the fermentation and milling process of corn and wheat, respectively. The remaining components of the kernel, such as fiber, increase in concentration, which causes most grain co-products to be low in dietary energy. Both DDGS and midds have higher crude fiber content than corn and contain more arabinoxylans. Arabinoxylans are hydrophilic non-starch polysaccharides (NSP) found in grain as minor constituents in the cell wall that act as anti-nutritional factors. Swine do not digest NSP efficiently due to their lack of fiber-specific digestive enzymes; consequently, enzymes like xylanase are viable solutions to increase nutrient availability.

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[1] Appreciation is expressed to Danisco Animal Nutrition, St. Louis, MO, for their financial support of this project.

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Xylanase is a carbohydrase that is able to break some insoluble bonds that monogastric animals are otherwise unable to digest (Sugimoto and Van Buren, 1970[3]). Xylanase also has been successful in increasing nutrient digestibility of swine diets (Nortey et al., 2008[4]); however, corn is more digestible and lower in fiber than wheat, which is one factor believed to contribute to xylanase's inconsistency in improving growth performance when used in corn-soy–based diets (Jacela et al., 2009[5]). Xylanase may be more beneficial in corn-soybean meal–based diets when the diets contain high levels of higher-fiber ingredients such as DDGS and midds; therefore, the objective of this study was to evaluate the effect of xylanase in corn-soybean meal–based diets with high co-product inclusion (15% wheat midds and 30, 42.5, or 50% DDGS) on dietary nutrient digestibility.

Procedures

The Institutional Animal Care and Use Committees at Kansas State University and Danisco Animal Nutrition approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Farm. Pigs were housed in an environmentally controlled finishing building with pens over a totally slatted floor that provided approximately 10 ft^2/pig. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. The facility was a mechanically ventilated room with a pull-plug manure storage pit.

A total of 18 barrows and 18 gilts (337 × 1050, PIC, Hendersonville, TN; initially 185 lb BW) were individually penned and used in a 14-d experiment. Prior to being assigned to treatment diets, all pigs were fed a corn-soybean meal–based diet with 30% DDGS and 10% midds. All pigs were then assigned to a pen, and treatments were balanced by gender and initial BW and randomly allotted to 1 of 6 dietary treatments with 3 replications per gender (6 replications per treatment). The 6 treatments consisted of corn-soybean meal–based diets with 15% added midds and were arranged in a 2 × 3 factorial with the main effects of xylanase (0 or 4,000 units xylanase per kilogram of diet; Porzyme 93020) and DDGS (Homeland Energy, Lawler, IA; 35%, 42.5%, or 50%). All diets were fed in meal form and manufactured at United Farmers Cooperative (Klossner, MN). In addition, all diets were formulated to contain 1,000 phytase units (FTU)/kg phytase (Table 1). Pigs were allowed ad libitum access to food and water. Diets were formulated to meet all requirements recommended by NRC (1998[6]).

Feces samples were collected on the morning and night of d 14 via rectal massage from all pigs. All diets contained 0.4% titanium dioxide (TiO^2) as the digestibility marker. Samples of feces were stored in a freezer (-4°F) until they were thawed and homogenized for each pig. Fecal samples were dried at 122°F in a forced-air oven, then ground for analysis of bomb calorimetry and TiO^2 concentration.

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[3] Sugimoto, H., and J. P. Van Buren. 1970. Removal of oligosaccharides from soy milk by an enzyme from Aspergillussaitoi. J. Food Sci. 35:655–660.
[4] Nortey, T. N., J. F. Patience, J. S. Sands, N. L. Trottier, and R. T. Zijlstra. 2008. Effects of Xylanase supplementation on the apparent digestibility and digestible content of energy, amino acids, phosphorus, and calcium in wheat and wheat by-products from dry milling fed to grower pigs. J. Anim. Sci. 86:3450–3464.
[5] Jacela et al., Swine Day 2009, Report of Progress 1020, pp. 220–224.
[6] NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Gross energy of diets and ground fecal samples were determined with an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Diets and ground fecal samples were also analyzed for TiO^2 concentration with an atomic absorption spectrometer.

Diet samples were collected from the tops of each feeder and combined for a single composite sample by treatment to measure moisture, CP, crude fat, GE, ADF, NDF, Ca, and P at Eurofins US (Des Moines, IA). Fecal samples were also analyzed for CP, crude fat, GE, ADF, NDF, Ca, and P.

Xylanase activity was analyzed at Eurofins US (Des Moines, IA) in which 1 unit of xylanase activity (XU) is defined as the amount of xylanase that will liberate 0.5 µmol of reducing sugars (expressed as xylose equivalents) from a cross-linked oat spelt xylan substrate (at pH 5.3 and 122°F in 1 min).

Data were analyzed as a 2 × 3 factorial using the PROC MIXED procedure in SAS (SAS Institute, Inc., Cary, NC) with pig as the experimental unit. Linear and quadratic polynomial contrasts were conducted to determine effects of increasing dietary DDGS. Results were considered significant at $P \leq 0.05$ and trends at $P \leq 0.10$.

Results and Discussion

Chemical Analysis

Nutrient analyses of the treatment diets were found to be generally similar to formulation (Table 2). The only exception was the Ca level, which was much lower than anticipated in the low-DDGS with xylanase diet. We speculated that limestone was omitted from this diet during manufacturing. The other minor differences were not expected to influence the results of the experiment.

Treatment diets containing xylanase were formulated to contain 4,000 units of xylanase activity per kilogram of diet. Chemical analysis showed some variation in diet xylanase concentrations, but on average, the treatments with the enzyme had significantly higher levels of xylanase activity than those without xylanase, which indicates that xylanase was included in the correct diets.

Nutrient Digestibility

Enzyme × DDGS interactions ($P < 0.05$) were observed for all nutrient digestibility criteria tested (Table 3). The majority of these interactions were a result of differences in response to increasing DDGS with and without xylanase. In diets with xylanase, apparent digestibility generally decreased as DDGS increased. In diets without xylanase, apparent digestibility decreased as DDGS increased from 35 to 42.5% but increased in diets containing 50% DDGS. Apparent digestibility of NDF decreased ($P < 0.01$), but digestibility of Ca increased ($P < 0.001$) with the addition of dietary xylanase; however, Ca digestibility could have been artificially high due to the low level of Ca present in the treatment diet, making pigs more efficient in their utilization of Ca.

Pigs fed diets with increasing DDGS in combination with added xylanase demonstrated reduced (linear, $P < 0.02$) digestibility of DM, CP, GE, Ca, P, and fat as well as reduced (quadratic, $P < 0.01$) ADF, NDF, and Zn digestibility; however, when dietary DDGS increased without added xylanase, we observed increased (quadratic, $P < 0.05$)

digestibility of DM, CP, GE, ADF, NDF, and ADF but reduced (quadratic, $P < 0.05$) apparent fecal digestibility of Ca, P, and Zn (Table 4). This result was driven mainly by the unexplained increase in digestibility when pigs were fed 50% DDGS without the enzyme.

Increasing DDGS regardless of added xylanase also decreased (quadratic, $P < 0.01$) apparent fecal digestibility of DM, GE, ADF, NDF, and Zn and decreased (linear, $P < 0.02$) fecal digestibility of fat, Ca, and P (Table 5). In this study, adding dietary xylanase was unsuccessful at improving digestibility in corn-soybean meal–based diets containing fibrous co-products for finishing pigs.

Table 1. Diet composition (as-fed basis)

	DDGS, %[1]		
Item	35	42.5	50
Ingredient, %			
Corn	34.80	28.40	22.00
Soybean meal (46.5% CP)	11.95	10.73	9.50
DDGS	35.00	42.50	50.00
Wheat middlings	15.00	15.00	15.00
Choice white grease	1.00	1.00	1.00
Limestone	1.45	1.56	1.67
Salt	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10
L-lysine HCl	0.20	0.22	0.23
Phytase[2]	0.04	0.04	0.04
Xylanase[3]	---	---	---
Total	100.0	100.0	100.0
Calculated analysis			
Standardized ileal digestible (SID) AA			
Lysine, %	0.79	0.79	0.79
Methionine:lysine, %	39	41	42
Met & Cys:lysine, %	79	83	86
Threonine:lysine, %	73	75	77
Tryptophan:lysine, %	21	21	21
Total lysine, %	0.95	0.97	0.98
CP, %	20.4	21.3	22.2
SID lysine:ME, g/Mcal	2.37	2.37	2.37
ME, kcal/lb	1,512	1,511	1,509
Ca, %	0.64	0.68	0.71
Available P, %	0.47	0.52	0.56
Crude fat, %	6.9	7.4	7.9
Crude fiber, %	5.0	5.4	5.8
NDF, %	18.5	19.7	20.8
ADF, %	6.9	7.5	8.0

[1] DDGS: dried distillers grains with solubles (Homeland Energy, Lawler, IA).
[2] Phyzyme 2,500 (Danisco Animal Nutrition, St. Louis, MO) provided 1,000 phytase units (FTU)/kg phytase with a release of 0.14%.
[3] Porzyme 9302 (Danisco Animal Nutrition, St. Louis, MO) was added at the expense of corn to create the xylanase diets.

Table 2. Chemical analysis of diets (as-fed basis)

	Xylanase:[1]	-			+		
Item	DDGS, %:[2]	35	42.5	50	35	42.5	50
DM, %		90.0	90.2	90.0	89.8	89.6	89.7
CP, %		20.3	21.6	21.7	22.1	22.0	22.5
GE, kcal/lb		1,910	1,940	1,940	1,960	1,950	1,930
ADF, %		6.7	7.1	7.2	6.8	7.1	8.1
NDF, %		19.3	19.6	20.7	18.2	19.2	22.5
Fat, %		6.4	7.6	7.9	6.1	6.4	6.6
Ca, %		0.93	1.14	1.35	0.32	0.81	1.13
P, %		0.65	0.75	0.78	0.64	0.71	0.73
Zn, %		314	306	382	314	230	228
Phytase, FTU/kg[3]		1,430	2,150	2,470	1,010	1,400	1,360
Xylanase activity, U/kg[4]		330	310	420	4,700	2,700	3,700

[1] Porzyme 9302 (Danisco Animal Nutrition, St Louis, MO).
[2] DDGS: dried distillers grains with solubles (Homeland Energy, Lawler, IA).
[3] FTU: phytase units.
[4] One unit of xylanase activity is defined as amount of xylanase that will liberate 0.5 μmol of reducing sugars from a cross-linked oat spelt xylan (at pH 5.3 and 122°F) substrate in 1 min.

Table 3. Effect of dietary xylanase and dried distillers grains with solubles (DDGS) on finishing pig apparent total tract digestibility[1]

	Xylanase:[2]	-			+			
Item	DDGS, %:	35	42.5	50	35	42.5	50	SEM
DM		74.83	69.93	75.72	77.42	71.64	68.32	1.15
CP		78.74	77.64	82.11	80.72	77.81	76.56	1.21
GE		74.09	69.72	75.75	77.40	70.66	67.26	1.28
ADF		37.18	32.74	49.78	42.47	32.51	38.12	2.63
NDF		49.86	42.72	58.14	49.39	40.54	47.48	2.24
Fat		47.54	44.34	51.67	54.93	46.09	33.03	3.94
Ca		48.70	25.89	32.39	62.62	53.87	35.00	4.00
P		39.82	30.51	39.21	48.07	43.29	30.71	3.97
Zn		13.11	-18.48	12.01	15.95	-7.70	-2.62	4.28

[1] Fecal samples were collected on d 14 via rectal massage from all pigs.
[2] Porzyme 9302 (Danisco Animal Nutrition, St Louis, MO).

Table 4. Main effects of dietary xylanase and dried distillers grains with solubles (DDGS) on finishing pig apparent total tract digestibility[1]

	DDGS, %				Xylanase		
Item, %	35	42.5	50	SEM	No	Yes	SEM
DM	76.13	70.79	72.02	0.77	73.50	72.46	0.64
CP	79.73	77.72	79.34	0.81	79.50	78.60	0.67
GE	75.75	70.19	71.50	0.96	73.18	71.77	0.77
ADF	39.83	32.63	43.95	1.78	39.90	37.70	1.34
NDF	49.62	41.63	52.81	1.50	50.24	45.80	1.21
Fat	51.23	45.22	42.35	2.64	47.85	44.68	2.12
Ca	55.66	39.88	33.70	2.68	35.66	50.50	2.15
P	43.94	36.90	34.96	2.66	36.51	40.69	2.13
Zn	14.53	-13.09	4.69	3.21	2.21	1.88	2.57

[1] Fecal samples were collected on d 14 via rectal massage from all pigs.

Table 5. Effects of dietary xylanase and DDGS on finishing pig apparent total tract digestibility[1]

	Probability, *P*<							
Xylanase:[2]					-	-	+	+
Item, %	Interaction[3]	Xylanase[4]	DDGS lin.[5]	DDGS Quad[5]	DDGS lin.[6]	DDGS quad[6]	DDGS lin.[7]	DDGS quad[7]
DM	0.001	0.25	0.001	0.002	0.55	0.001	0.001	0.36
CP	0.01	0.23	0.73	0.08	0.04	0.05	0.02	0.57
GE	0.001	0.20	0.004	0.01	0.37	0.003	0.001	0.31
ADF	0.01	0.25	0.09	0.001	0.001	0.001	0.19	0.01
NDF	0.05	0.01	0.14	0.001	0.01	0.001	0.51	0.004
Fat	0.004	0.29	0.02	0.61	0.42	0.24	0.001	0.64
Ca	0.01	0.001	0.001	0.15	0.004	0.01	0.001	0.27
P	0.02	0.17	0.02	0.42	0.90	0.05	0.004	0.39
Zn	0.03	0.93	0.04	0.001	0.86	0.001	0.01	0.01

[1] Fecal samples were collected on d 14 via rectal massage from all pigs.
[2] Porzyme 9302 (Danisco Animal Nutrition, St. Louis, MO).
[3] Interactive effect (xylanase × DDGS).
[4] Main effect of xylanase inclusion (Treatments 1, 2, and 3 vs. 4, 5, and 6).
[5] Effect of DDGS regardless of xylanase inclusion (Treatments 1 & 4, 2 & 5, and 3 & 6).
[6] Effect of DDGS without xylanase (Treatments 1, 2, and 3).
[7] Effect of DDGS with xylanase (Treatments 4, 5, and 6).

Effect of Dietary Addition of Denagard (Tiamulin) and CTC (Chlortetracycline) on Pig Performance Immediately after Placement in the Finishing Barn[1]

S. Nitikanchana,[2] S. S. Dritz,[2] M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

A total of 1,313 pigs (PIC 1050 × 337; initially 49 lb) were used in a 35-d study to determine the effects of adding Denagard (Tiamulin) and CTC (chlortetracycline) to feed on pig performance immediately after placement in the finisher barn. Pigs were transported from one nursery facility and placed into the finishing barn without maintaining pen integrity. Immediately after placement in the finishing barn, pens of pigs were weighed and randomly allotted to treatments arranged in a 2 × 2 factorial with main effects of Denagard (0 and 35 g/ton; Novartis Animal Health, Greensboro, NC) and chlortetracycline (CTC; 0 and 400 g/ton). Diets were corn-soybean meal–based and contained 20% bakery and 35% dried distiller's grains with solubles (DDGS). Treatment diets were fed from d 0 to 15 with a common non-medicated diet fed from d 15 to 35.

An interaction ($P < 0.01$) was observed for ADFI from d 0 to 15 and for the overall period, with pigs fed the diet without medication and the combination of Denagard and CTC having greater ADFI than either medication alone. Adding antibiotics to the diets also improved F/G from d 0 to 15, with no differences among pigs fed Denagard, CTC, or their combination (Denagard × CTC interaction, $P < 0.01$). Adding Denagard or CTC to diets improved ($P < 0.01$) ADG and F/G from d 0 to 15; however, when the antimicrobials were removed from the diet (d 15 to 35), ADG of pigs previously fed any of the medicated diets decreased (Denadard $P < 0.01$; CTC $P < 0.06$) compared with pigs previously fed the non-medicated diet. Because the advantages in growth performance from d 0 to 15 were lost during the period from d 15 to 35, there were no differences ($P > 0.15$) in overall ADG or F/G. In conclusion, adding Denagard and/or CTC to diets immediately after pig placement in the finisher can improve growth performance, but the performance was not maintained in the subsequent period when pigs were fed non-medicated diets.

Key words: antibiotics, chlortetracycline, Denagard, finishing pig

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance

[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Introduction

Feed medications have been widely used in the swine industry for prevention of disease and improvement of growth performance. Several trials (Steindinger et al., 2010[3]; Sotak et al., 2011[4]) have observed that nursery pigs fed diets with Denagard and CTC had greater ADG, ADFI, or improved F/G than pigs fed non-medicated diets. Movement of pigs from the nursery into the finishing facility can be a stressful period for pigs, and commingling pigs from multiple nursery pens into finishing pens may also expose pigs to new pathogens. Therefore, the advantage of feed medication might be maximized after pigs are moved from the nursery to the finisher barn. This trial was conducted to investigate the effects of dietary addition of Denagard and/or CTC on growth performance of growing pigs immediately after placement in the finisher barn.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Twenty-four pens were equipped with conventional dry stainless steel feeders (STACO, Inc., Schaefferstown, PA) with 5 holes and a cup waterer in each pen for ad libitum access to feed and water. The remaining 24 pens were equipped with a double-sided wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE), with the feeder as the only source of water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 1,313 pigs (PIC 1050 × 337; initially 49 lb) were used in a 35-d study. Pigs were transported from one nursery facility and placed into the finishing barn without maintaining pen integrity. At placement into the finishing barn, a similar number of barrows and gilts were randomly placed in each pen, with 31 to 33 pigs per pen and 10 pens per treatment blocked by weight and feeder type. Treatments were arranged in a 2 × 2 factorial with main effects of Denagard (0 and 35 g/ton; Novartis Animal Health, Greensboro, NC) and chlortetracycline (CTC; 0 and 400 g/ton). Diets were corn-soybean meal–based and contained 30% bakery product and 35% dried distiller's grains with solubles (DDGS; Table 1). Treatment diets were fed from d 0 to 15, and a common, non-medicated diet was fed from d 15 to 35. Pens of pigs were weighed and feed disappearance was recorded at d 15 and 35 to determine ADG, ADFI, and F/G.

The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Treatments were arranged in a 2 × 2 factorial and data were analyzed for the main effects of Denagard and CTC, and their interaction. Pen was the experimental unit for all data analysis, and significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

Results and Discussion

From d 0 to 15, pigs fed diets containing Denagard or CTC alone had decreased feed intake than pigs fed the non-medicated diet or the diet containing both Denagard and

[3] Steidinger et al., Swine Day 2009, Report of Progress 1020, pp. 122–131.

[4] Sotak et al., Swine Day 2010, Report of progress 1038, pp. 72–78.

CTC (Denagard × CTC interaction, $P < 0.01$; Table 2). Adding Denagard or CTC to the diet improved F/G with no additive response, which also led to a Denagard × CTC interaction ($P < 0.01$). The ADFI interaction from d 0 to 15 led to a similar interaction ($P = 0.05$) for ADFI for the overall period (d 0 to 35), with pigs fed non-medicated diets or the combination of Denagard and CTC having greater ADFI than pigs fed diets containing only Denagard or CTC alone. For main effects, from d 0 to 15, adding Denagard or CTC to diets improved ($P < 0.01$) ADG and F/G with an additive response in ADG.

From d 15 to 35, when a common non-medicated diet was fed, pigs previously fed Denagard ($P < 0.01$) and CTC ($P < 0.06$) had decreased ADG compared with pigs previously fed the non-medicated control diet. Feed efficiency of pigs previously fed Denagard also had poorer ($P < 0.01$) F/G from d 15 to 35. Because the growth advantage from d 0 to 15 was lost during the subsequent period from d 15 to 35, no differences ($P > 0.18$) were observed in overall (d 0 to 35) performance.

The results of this experiment are consistent with previous trials (Steidinger et al., 2010[5]; Sotak et al., 2011[6]) that found an improvement in growth rate and feed efficiency when adding antibiotics to diets; however, the benefit in growth performance was lost in the subsequent period in this trial, resulting in no benefit for the overall period. The growth rate response to Denagard and CTC also was additive, because pigs fed the combination of Denagard and CTC had greater ADG than pigs fed diets with only Denagard or CTC.

In conclusion, adding Denagard /CTC to grower diets immediately after placement in the finishing barn improved growth performance, but the performance benefit was not maintained in the subsequent period when pigs were fed non-medicated diets.

[5] Steidinger et al., Swine Day 2009, Report of Progress 1020, pp. 122–131
[6] Sotak et al., Swine Day 2010, Report of progress 1038, pp. 72–78.

Table 1. Diet composition

Item	Treatment diet[1]	Common diet
Ingredient, %		
Corn	10.99	3.80
Soybean meal, 46.5% CP	21.52	13.54
Bakery by-product	30.00	30.00
DDGS[2]	35.00	50.00
Limestone	1.31	1.48
Salt	0.35	0.35
Vitamin-trace mineral premix	0.10	0.10
L-threonine	0.02	---
L-lysine sulfate	0.72	0.72
Phytase[3]	0.005	0.005
Denagard[4]	---	---
Chlortetracycline[5]	---	---
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.16	1.02
Isoleucine:lysine	67	71
Leucine:lysine	164	195
Methionine:lysine	30	35
Met & Cys:lysine	61	72
Threonine:lysine	61	65
Tryptophan:lysine	17.0	17.0
Valine:lysine	77	86
Total lysine, %	1.35	1.23
ME, kcal/lb	1,541	1,547
SID lysine:ME, g/Mcal	3.41	2.99
CP, %	23.7	23.6
Ca, %	0.62	0.66
P, %	0.50	0.53
Available P, %	0.32	0.38

[1] Treatment diets were fed from d 0 to 15, then a non-medicated common diet was fed from d 15 to 35.
[2] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).
[4] Denagard (Tiamulin, Novartis Animal Health, Greensboro, NC) was added in place of corn at 0.175% to provide a 35 g/ton of Denagard in the treatment diet.
[5] Chlortetracycline (CTC) was added in place of corn at 0.22% to provide 400 g/ton of CTC in the treatment diet.

Table 2. Effects of Denagard (Tiamulin) and chlortetracycline (CTC) fed immediately after placement on growing pig performance[1]

						Probability, $P<$		
Item	No medication	Denagard[2] 35 g/ton	CTC 400 g/ton	Denagard 35 g/ton + CTC 400 g/ton	SEM	Denagard × CTC	Denagard	CTC
d 0 to 15[3]								
ADG, lb	1.43	1.49	1.51	1.59	0.017	0.63	0.01	0.01
ADFI, lb	2.60	2.33	2.42	2.57	0.032	0.01	0.07	0.35
F/G	1.82	1.56	1.60	1.61	0.026	0.01	0.01	0.01
d 15 to 35								
ADG, lb	2.03	1.92	1.95	1.88	0.028	0.48	0.01	0.06
ADFI, lb	4.16	4.20	4.12	4.18	0.082	0.88	0.51	0.71
F/G	2.05	2.19	2.11	2.22	0.040	0.71	0.01	0.30
d 0 to 35								
ADG, lb	1.77	1.73	1.76	1.76	0.016	0.36	0.18	0.60
ADF, lb	3.49	3.40	3.39	3.49	0.047	0.05	0.92	0.90
F/G	1.97	1.96	1.92	1.98	0.024	0.15	0.28	0.61
BW, lb								
d 0	48.9	48.9	48.9	48.9	0.867	0.96	0.98	0.99
d 15	70.3	71.2	71.6	72.9	0.874	0.81	0.20	0.10
d 35	111.1	109.6	110.6	110.8	1.041	0.44	0.52	0.72

[1] A total of 1,313 pigs (initial BW 49 lb) were used in a 35-d trial. Pigs were randomly allotted to 1 of 4 dietary treatments with 31 to 33 pigs/pen and 10 pens per treatment.
[2] Denagard (0 and 35 g/ton; Novartis Animal Health, Greensboro, NC).
[3] Treatment diets were fed from d 0 to 15, then a non-medicated common diet was fed from d 15 to 35.

Effects of Source and Level of Added Zinc on Growth Performance and Carcass Characteristics of Finishing Pigs Fed Ractopamine HCl[1]

C. B. Paulk, M. D. Tokach, J. L. Nelssen, J. M. Gonzalez, J. M. DeRouchey, R. D. Goodband, and S. S. Dritz[2]

Summary

A total of 312 pigs (PIC 327 × 1050; initially 206.1 lb) were used in a 27-d study to determine the effects of increasing added Zn from zinc oxide (ZnO; Zinc Nacional S.A., Monterrey, Mexico) or Availa-Zn (Zinpro, Eden Prairie, MN) on growth performance and carcass characteristics of finishing pigs fed Ractopamine HCL (RAC; Paylean; Elanco Animal Health, Greenfield, IN). Pigs were allotted to 1 of 6 dietary treatments in a completely randomized design with 2 pigs per pen and 26 pens per treatment completed over 2 consecutive groups of finishing pigs (13 pens per treatment per group). Dietary treatments consisted of (1) a corn-soybean meal–based negative control diet (0.66% standardized ileal digestible [SID] lysine); (2) a positive control diet (0.92% SID lysine) containing 10 ppm RAC; (3), (4), and (5) RAC plus 50, 100, and 150 ppm added Zn from ZnO, respectively; and (6) RAC plus 50 ppm added Zn from Availa-Zn. The trace mineral premix provided a basal level of 83 ppm Zn from Zn Sulfate ($ZnSO_4$) in all diets.

Overall, pigs fed the positive control RAC diet had improved ($P < 0.05$) ADG, F/G, income over feed cost (IOFC), final BW, HCW, carcass ADG, carcass F/G, carcass IOFC, carcass yield, boneless loin weight, and a tendency for reduced ($P < 0.08$) ADFI compared with pigs fed the negative control diet. Pigs fed RAC with up to 150 ppm added Zn from ZnO had numerically improved (linear, $P < 0.09$) F/G, IOFC, caloric efficiency on an ME and NE basis, and a tendency toward increased (quadratic, $P < 0.06$) boneless loin weights. In addition, carcass ADG tended to increase (quadratic, $P < 0.09$) with increasing ZnO, with little improvement beyond feeding 50 ppm added Zn. Overall, pigs fed diets with 50 ppm added Zn from Availa-Zn had increased ($P < 0.05$) IOFC, carcass ADG, and a tendency for increased ($P < 0.06$) ADG compared with pigs fed positive control, RAC diet. No differences were observed in performance ($P > 0.10$) among pigs fed diets with 50 ppm added Zn from ZnO or Availa-Zn.

These data indicate that adding up to 150 ppm Zn from ZnO or 50 ppm Zn from Availa-Zn in finishing pig diets containing RAC can improve performance and IOFC; however, more research is needed to better define the response and understand the mechanism responsible for the improved performance from added Zn.

Key words: Ractopamine HCl, zinc, finishing pig

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[1] Appreciation is expressed to Farmland Foods Inc., Roger Johnson, and Cory Rains for carcass data collection.

[2] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Introduction

Ractopamine HCl (RAC; Paylean; Elanco Animal Health, Greenfield, IN) is frequently added to finishing pig diets to improve growth performance and carcass leanness. When adding RAC to finishing diets, amino acid concentrations are generally increased approximately 30% to maximize growth and carcass lean based on growth modeling results and several research trial datasets. Little research has been conducted to determine the effects of trace mineral concentrations on the response to RAC, but recent studies have observed that added Zn can increase the response to RAC (Akey, 2011[3], Patience, 2011[4]). We designed an experiment to determine the effects of adding various concentrations of added Zn from zinc oxide (50, 100, or 150 ppm ZnO or 50 ppm added Zn from Availa-Zn on growth performance and carcass characteristics of finishing pigs fed RAC.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The project was conducted at the K-State Swine Teaching and Research Center. Pigs were housed in an environmentally controlled finishing building with pens that were 5 ft × 5 ft with totally slatted flooring. Each pen was equipped with a dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

A total of 312 finishing pigs (PIC 327 × 1050, two consecutive groups of 156 pigs) with an initial BW of 206.1 lb were used in this study. Pens of pigs were allotted to 1 of 6 dietary treatments, with either 2 barrows or 2 gilts per pen and 26 pens per treatment. Dietary treatments consisted of: (1) a corn-soybean meal–based negative control diet formulated to 0.66% SID lysine; (2) a positive control diet formulated to contain 0.92% SID lysine and 10 ppm RAC; (3), (4), and (5) the RAC diet plus 50, 100, and 150 ppm added Zn from ZnO, respectively; and (6) RAC plus 50 ppm added Zn from Availa-Zn (Table 1). Basal diets contained 83 ppm Zn from $ZnSO_4$ provided by the trace mineral premix. Experimental diets were fed in meal form, and ZnO or Availa-Zn was added to the RAC diet at the expense of corn. Pigs and feeders were weighed on d 0, 14, and 27 to determine ADG, ADFI, F/G, IOFC, and caloric efficiency on an ME and NE basis.

Caloric efficiency is a measurement of the efficiency of energy usage, or the ME or NE required per pound of gain. Metabolizable energy values of the feed ingredients were derived from NRC (1998[5]), and NE values of the feed ingredients were derived from INRA (2004[6]). Income over feed cost, a method to measure an economic value, was also calculated and assumed that other costs, such as utility and labor, were equal and the only variables were ADG and feed usage for the experimental period. Corn was valued

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[3] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.

[4] Patience, J. P. 2011. Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. IA St. Univ. Anim. Ind. Rep.

[5] NRC. 1998. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

at $225/ton, soybean meal at $316/ton, L-lysine at $1.10/lb, DL-methionine at $2.70/lb, L-threonine at $1.25/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb, and pig price at $0.61/lb live weight.

On d 27, both groups of pigs were weighed, tattooed, and shipped to a commercial packing plant (Farmland Foods Inc., Crete, NE) for calculation of HCW and percentage carcass yield. For the second group of pigs, last-rib ruler backfat measurements, percentage lean, and boneless loin weights were collected. Percentage carcass yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant. Percentage lean was calculated by dividing the standardized fat-free lean (SFFL) by HCW. The following equation was used for calculation of SFFL (NPPC, 2001[7]):

$$\text{Lb. SFFL} = 23.568 + 0.503 \times (\text{HCW, lb}) - 21.348 \times (\text{last-rib backfat thickness, in.})$$

To calculate carcass ADG and F/G, an initial carcass weight was estimated by multiplying initial live weight by a 75% yield value. Carcass-based IOFC was calculated using the same ingredient prices and carcass was priced at $0.87/lb.

All data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In addition to treatment, the effects of gender and group were included as fixed effects. Hot carcass weight was used as a covariate for analyses of backfat thickness and boneless loin weight. Contrast statements consisted of: (1) negative control vs. positive control RAC diet, (2) increasing ZnO linear and quadratic polynomials, (3) positive control RAC diet vs. Availa-Zn, and (4) 50 ppm added Zn from ZnO vs Availa-Zn. Statistical significance was determined at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

From d 0 to 14, pigs fed the positive control RAC diet had improved ($P < 0.01$) ADG, F/G, IOFC, and caloric efficiencies on both a ME and NE basis compared with pigs fed the negative control diet (Table 2). Pigs fed RAC with up to 150 ppm added Zn from ZnO had numerically improved (linear, $P < 0.09$) IOFC. Pigs fed RAC plus Availa-Zn had increased ($P < 0.05$) ADG, IOFC, caloric efficiency on a ME basis and a tendency for improved ($P < 0.06$) F/G and caloric efficiency on a NE basis compared with pigs fed only RAC. No differences in performance ($P > 0.12$) were found between pigs fed diets containing 50 ppm added Zn from ZnO vs. Availa-Zn.

From d 14 to 27, pigs fed the positive control RAC diet had reduced ($P < 0.02$) ADFI, F/G, and caloric efficiency on an ME and NE basis and a tendency for increased ($P < 0.06$) ADG compared with the negative control diet. No differences were observed in performance ($P > 0.24$) between pigs fed RAC and diets containing added Zn from ZnO or Availa-Zn. Performance did not differ ($P > 0.60$) in pigs fed diets with 50 ppm added Zn from ZnO vs. Availa-Zn.

[7] NPPC 2001. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Counc., Des Moines, IA.

Overall (d 0 to 27), pigs fed RAC had improved ($P < 0.05$) ADG, F/G, IOFC, final BW, HCW, carcass ADG, carcass F/G, carcass IOFC, percentage carcass yield, and boneless loin weight and a tendency for reduced ($P < 0.08$) ADFI compared with those fed the negative control diet (Table 3). Pigs fed RAC with up to 150 ppm added Zn from ZnO had numerically improved (linear, $P < 0.09$) F/G, IOFC, caloric efficiencies on a ME and NE basis, and a tendency for increased (quadratic, $P < 0.06$) boneless loin weights. In addition, carcass ADG tended to increase (quadratic, $P < 0.09$) with increasing ZnO, with little improvement beyond feeding 50 ppm added Zn. Pigs fed diets with 50 ppm added Zn from Availa-Zn also had a tendency for increased ($P < 0.06$) ADG, and had increased ($P < 0.05$) IOFC and carcass ADG compared with pigs fed the positive control RAC diet. No differences were observed in performance ($P > 0.38$) between pigs fed diets with 50 ppm added Zn from ZnO vs. Availa-Zn.

The addition of RAC to the diet of finishing pigs improved ADG, F/G, IOFC, and carcass-based IOFC by 16%, 18%, $2.85, and $5.09, respectively, compared with pigs fed the negative control diet. The addition of 150 ppm Zn from ZnO to the RAC diet numerically improved F/G by 3.4% and IFOC by $1.50 compared with the RAC-only diet. The addition of 50 ppm Zn from Availa-Zn to the RAC diet numerically improved ADG by 4.6%, resulting in increased IOFC of $1.62 per pig compared with the RAC-only diet. These data indicate that adding up to 150 ppm Zn from ZnO or 50 ppm Zn from Availa-Zn in finishing pig diets containing RAC can improve performance and IOFC; however, more research is needed to better define the response and understand the mechanism of action for the added Zn.

Table 1. Diet composition (as-fed basis)[1,2]

Item	Control	RAC
Ingredient, %		
Corn	84.29	73.91
Soybean meal, (46.5% CP)	13.65	24.00
Monocalcium P, (21% P)	0.50	0.45
Limestone	0.90	0.90
Salt	0.35	0.35
Vitamin premix	0.075	0.075
Trace mineral premix[3]	0.075	0.075
L-lysine HCl	0.15	0.15
DL-methionine	---	0.015
L-threonine	---	0.025
Ractopamine HCl[4]	---	0.05
Total	100	100
Calculated analysis, %		
Standardized ileal digestible (SID) amino acids, %		
Lysine	0.66	0.92
Isoleucine:lysine	71	70
Leucine:lysine	184	158
Methionine:lysine	32	30
Met & Cys:lysine	66	60
Threonine:lysine	64	64
Tryptophan:lines	19	19
Valine:lysine	85	79
Total lysine, %	0.75	1.03
CP, %	13.70	17.60
ME, kcal/lb[5]	1,520	1,518
NE, kcal/lb[6]	1,139	1,109
SID lysine: ME/Mcal	1.97	2.75
Ca, %	0.51	0.53
P, %	0.44	0.47
Available P, %	0.16	0.16

[1] Diets were fed in meal form from d 0 to 27 of the experiment.
[2] Dietary treatments were obtained by replacing corn in the RAC diet to achieve 50, 100, and 150 ppm added Zn from ZnO (Zinc Nacional S.A., Monterrey, Mexico) and 50 ppm added Zn from Availa-Zn (Zinpro, Eden Prairie, MN).
[3] Provided 83 ppm Zn from $ZnSO_4$.
[4] Provided 9 g/lb of Ractopamine HCl (Paylean; Elanco Animal Health, Greenfield, IN).
[5] ME values for ingredients were derived from NRC (1998).
[6] NE values for all ingredients were derived from INRA (2004).

Table 2. Effects of added zinc and Ractopamine HCl (RAC) on growth performance of finishing pigs[1]

			ZnO, ppm Zn			Availa-Zn, ppm Zn		Probability, *P*<				
									ZnO		Availa-Zn vs.	
	Control	RAC	50	100	150	50	SEM	Control vs RAC	Linear	Quadratic	RAC	50 ppm Zn (ZnO)
d 0 to 14												
ADG, lb	2.39	2.93	2.98	2.97	3.06	3.14	0.07	0.01	0.24	0.81	0.04	0.12
ADFI, lb	7.39	7.24	7.20	7.12	7.19	7.34	0.14	0.44	0.71	0.67	0.62	0.47
F/G	3.14	2.48	2.44	2.42	2.38	2.34	0.05	0.01	0.16	0.94	0.06	0.19
IOFC, $/pig[2]	7.19	9.78	10.31	10.38	10.95	11.28	0.47	0.01	0.09	0.96	0.03	0.15
Caloric efficiency[3]												
ME	4,767	3,770	3,701	3,670	3,613	3,549	79	0.01	0.16	0.94	0.05	0.18
NE	3,272	2,547	2,501	2,480	2,441	2,398	54	0.01	0.16	0.94	0.06	0.19
d 14 to 27												
ADG, lb	2.18	2.36	2.46	2.42	2.37	2.41	0.07	0.06	0.99	0.26	0.57	0.66
ADFI, lb	7.21	6.71	6.88	6.75	6.57	6.84	0.14	0.02	0.39	0.24	0.55	0.85
F/G	3.38	2.89	2.83	2.83	2.80	2.85	0.07	0.01	0.39	0.87	0.68	0.88
IOFC, $/pig[2]	5.35	5.60	6.04	6.04	5.94	5.73	0.42	0.67	0.60	0.52	0.83	0.60
Caloric efficiency[3]												
ME	5,137	4,382	4,297	4,299	4,247	4317	104	0.01	0.39	0.87	0.66	0.89
NE	3,525	2,961	2,903	2,905	2,869	2917	70	0.01	0.39	0.87	0.67	0.89

continued

Table 2. Effects of added zinc and Ractopamine HCl (RAC) on growth performance of finishing pigs[1]

			ZnO, ppm Zn			Availa-Zn, ppm Zn		Probability, *P*<				
									ZnO		Availa-Zn vs.	
	Control	RAC	50	100	150	50	SEM	Control vs RAC	Linear	Quadratic	RAC	50 ppm Zn (ZnO)
d 0 to 27												
ADG, lb	2.28	2.66	2.73	2.71	2.72	2.79	0.05	0.01	0.38	0.57	0.06	0.38
ADFI, lb	7.30	6.99	7.04	6.94	6.89	7.10	0.12	0.08	0.49	0.68	0.53	0.76
F/G	3.21	2.63	2.59	2.57	2.54	2.55	0.04	0.01	0.09	0.91	0.12	0.46
IOFC, $/pig[2]	12.54	15.39	16.35	16.42	16.89	17.01	0.59	0.01	0.08	0.68	0.05	0.43
Caloric efficiency[3]												
ME	4,881	3,996	3,927	3,905	3,850	3861	60	0.01	0.09	0.91	0.12	0.44
NE	3,350	2,700	2,653	2,638	2,601	2609	40	0.01	0.09	0.91	0.12	0.45
Weight, lb												
d 0	206.0	206.1	205.8	204.9	206.5	206.5	1.50	0.96	0.98	0.54	0.85	0.75
d 14	239.4	247.1	247.6	246.5	249.3	250.4	1.88	0.01	0.52	0.54	0.22	0.29
d 27	267.4	277.8	279.5	278.0	280.1	281.8	2.12	0.01	0.58	0.93	0.19	0.44

[1] A total of 312 pigs (PIC 327 × 1050; two consecutive groups of 156 pigs) were used in a 27-d study with 2 pigs per pen and 26 pens per treatment.
[2] IOFC: income over feed cost. Corn was valued at $225/ton, soybean meal at $316/ton, L-lysine at $1.10/lb, DL-methionine at $2.70/lb, L-threonine at $1.25/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb, and pig price at $0.61/lb.
[3] Caloric efficiency is expressed as kcal/lb gain.

Table 3. Effects of added zinc and ractopamine HCl (RAC) on carcass characteristics of finishing pigs[1]

								Probability, $P<$				
			ZnO, ppm Zn			Availa-Zn, ppm Zn			ZnO		Availa-Zn	
Item	Control	RAC	50	100	150	50 ppm Zn	SEM	Control vs. RAC	Linear	Quadratic	RAC	50 ppm Zn (ZnO)
Final wt, lb	267.4	277.8	279.5	278.0	280.1	281.8	2.12	0.01	0.58	0.93	0.19	0.44
HCW, lb	197.3	206.8	209.3	207.3	207.8	210.2	1.54	0.01	0.88	0.49	0.12	0.69
Carcass ADG, lb[2]	1.59	1.93	2.03	1.99	1.96	2.05	0.04	0.01	0.84	0.09	0.03	0.80
Carcass F/G, lb[2]	4.62	3.63	3.48	3.51	3.55	3.47	0.07	0.01	0.52	0.21	0.13	0.90
Carcass yield, %[3]	73.9	74.4	74.8	74.5	74.4	74.65	0.18	0.05	0.76	0.18	0.36	0.50
Back fat depth, in.[4,5]	0.97	0.93	0.93	0.92	0.88	0.90	0.04	0.43	0.26	0.52	0.50	0.47
Loin wt, lb[4,5]	8.52	8.92	8.74	8.88	9.10	8.81	0.12	0.02	0.17	0.06	0.46	0.68
Lean, %[4,5,6]	51.74	52.15	52.12	52.25	52.63	52.48	0.37	0.43	0.30	0.55	0.49	0.46
Carcass IOFC, $/pig[7]	147.22	152.31	154.31	152.97	153.54	154.74	1.17	0.01	0.65	0.54	0.15	0.79

[1] A total of 312 pigs (PIC 327 × 1050; two consecutive groups of 156 pigs) were used in a 27-d study with 2 pigs per pen and 26 pens per treatment.
[2] Initial carcass weight was calculated using a 75% yield value.
[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[4] Data were collected on the second group of pigs (13 pens per treatment).
[5] Adjusted using HCW as a covariate.
[6] Percentage lean was calculated by dividing the standardized fat-free lean (SFFL) by HCW. The equation used for calculation of SFFL was derived from NPPC (2001).
[7] Carcass IOFC: carcass-based income over feed cost. Corn was valued at $225/ton, soybean meal at $316/ton, L-lysine at $1.10/lb, DL-methionine at $2.70/lb, L-threonine at $1.25/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, Availa-Zn at $1.50/lb, and carcass price at $0.87/lb.

Effects of Added Zn in Diets with Ractopamine HCl on Growth Performance and Carcass Quality of Finishing Pigs in a Commercial Environment[1]

C. B. Paulk, M. D. Tokach, S. S. Dritz[2], J. L. Nelssen, J. M. DeRouchey, R. D. Goodband, and K. J. Prusa[3]

Summary
The experiment was conducted in a commercial facility to determine the effects of added Zn on the performance of finishing pigs fed Ractopamine HCl (RAC; Paylean®; Elanco Animal Health, Greenfield, IN). Pigs were randomly assigned to pens based on gender (14 barrow pens, 11 gilt pens, and 23 mixed-gender pens), with 25 to 28 pigs per pen. Previously, pens of pigs were assigned to treatments containing 0, 7.5, or 15% bakery by-product in a completely randomized design while balancing for initial BW and gender. On d 75, treatments were implemented to determine the effects of adding 50 ppm Zn from ZnO on finishing pig performance. A total of 1,234 pigs (PIC 337 × 1050; average BW 224.6 lb) were used in a 28-d study. Pens of pigs were randomly assigned to diets with and without 50 ppm added Zn from zinc oxide (ZnO) and balanced by BW, bakery by-product, and gender. All diets contained 5 ppm RAC and 83 ppm Zn from ZnO provided by the trace mineral premix. There were 24 pens per treatment.

Overall (d 75 to 102), no differences ($P > 0.22$) in growth performance or carcass characteristics were observed when pigs were fed diets with 50 ppm added Zn compared with the RAC control. For pigs subsampled on d 84, pigs fed diets with 50 ppm added Zn had decreased ($P < 0.05$) edge belly thickness compared with pigs fed the control. For pigs subsampled on d 102, pigs fed diets with 50 ppm added Zn had decreased ($P < 0.02$) backfat thickness, belly weight, and edge belly thickness; a tendency for decreased ($P < 0.07$) middle belly thickness; and increased ($P < 0.01$) percentage lean compared with pigs fed the RAC control. In contrast with our previous research, these data indicate that adding 50 ppm Zn from ZnO to finishing pig diets containing RAC did not improve overall performance. Consistent with the earlier research, income over feed cost (IOFC) was numerically increased with the addition of Zn.

Key words: finishing pig, Ractopamine HCl, zinc

Introduction
Ractopamine HCl (RAC; Paylean®; Elanco Animal Health, Greenfield, IN) is frequently added to finishing pig diets to improve growth performance and carcass

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.
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leanness. When adding RAC to finishing diets, amino acid concentrations are generally increased approximately 30% to maximize growth and carcass lean based on growth modeling results and several research trial data sets. In contrast, little research has been conducted to determine the effects of trace mineral concentrations on the response to RAC; however, recent research has observed that added Zn can increase the response to RAC (Akey, 2011[4], Patience, 2011[5]). We designed an experiment to determine the effects of adding zinc from ZnO on growth performance and carcass quality of finishing pigs supplemented RAC.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted in a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 5-hole stainless steel dry self-feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

The experiment was implemented on d 75 of a 102-d study designed to determine the effects of 0, 7.5, and 15% dietary bakery by-product on performance of finishing pigs. The procedures are described in another report (see Paulk et al., “Effects of Increasing Dietary Bakery By-Product on Growing-Finishing Pig Growth Performance and Carcass Quality,” p. 155).

On d 75, a total of 1,234 pigs (PIC 337 × 1050; average BW 224.6 lb) were used in a 28-d study. Pens of pigs were randomly assigned to diets (Table 1) with and without 50 ppm added Zn from ZnO and balanced by BW, bakery by-product level, and gender. All diets contained 5 ppm RAC and 83 ppm Zn from ZnO provided by the trace mineral premix. There were 24 pens per treatment.

To determine the effects of 50 ppm added Zn, pigs and feeders were weighed on d 75, 84, 91, and 102 to determine ADG, ADFI, F/G, IOFC, and caloric efficiency on an ME and NE basis. Caloric efficiency is a method to measure the efficiency of energy usage, or the ME or NE required per pound of gain. Metabolizable energy values of the feed ingredients and NE value of bakery by-product were derived from the NRC (1998) and NE values of the feed ingredients, except dietary bakery by-product, were derived from INRA (2004[6]). Income over feed cost, a method to measure an economic value, was also calculated and assumed that other costs, such as utility and labor, are equal, and the only variables are ADG and feed usage for the experimental period. Corn was valued at $220/ton, soybean meal at $400/ton, dried distillers grains with solubles (DDGS) at

[4] Akey. 2011. Effects of Zinc Source and Level in Paylean Diets on Pig Performance and Carcass Characteristics. Akey Swine Newsletter.

[5] Patience, J. P. 2011. Impact of Zinc Source and Timing of Implementation on Grow-finish Performance, Carcass Composition, and Locomotion Score. IA St. Univ. Anim. Ind. Rep.

[6] INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed materials, Sauvant, D., J-M. Perez and G. Tran, Eds. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

$210/ton, bakery by-product at $232/ton, Biolys at $0.70/lb, Optiphos 2000 at $2.65/lb, RAC at $35.26/lb, zinc oxide at $0.86/lb, and pig price at $0.61/lb.

On d 84, the 5 heaviest pigs from each pen (determined visually) were sold according to the normal marketing procedure of the farm. The middle weight pig from each of the 5 selected pigs was tattooed by pen and used for collection of carcass quality measurements; i.e., live weight at the plant, HCW, percentage carcass yield, backfat thickness, lean percentage, loin depth, kill floor pH, 4-hr pH, belly temperature, belly weight, middle belly thickness, edge belly thickness, belly firmness, belly fat iodine value (IV), loin pH, loin color, and marbling. Percentage lean was calculated by dividing the standardized fat-free lean (SFFL) by HCW. The following equation was used for calculation of SFFL (NPPC, 2001[7]):

$$\text{Lb. SFFL} = 15.31 + 0.51 \times (\text{HCW, lb}) - 31.277 \times (\text{last-rib backfat thickness, in.}) + 3.813 \times (\text{loin muscle depth, in.})$$

Belly firmness was determined using a subjective measurement taken by picking the belly up at its mid-point and estimating the amount of bend. The firmness scale was 1 = to very little bend, 2 = moderate or 50% bend, and 3 = belly ends touched. Loin color and marbling were taken on the exposed lean of the boneless loin (NPPC, 1999[8]). The loin color scale was from 1 to 6, with 1 = pale and 6 = dark. The marbling scores correspond to intramuscular lipid content, with 1 = very little to no intramuscular lipid content and 10 = extreme amounts. The selection of either a barrow or gilt from mixed-sex pens was balanced across treatments for determination of carcass quality. On d 102, the remaining pigs were individually tattooed by pen number and sent to harvest to allow for collection of carcass data. The middle-weight pig from each pen was selected for carcass quality measurements.

Data were analyzed using the PROC MIXED procedure in SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The interaction effects of increasing dietary bakery by-product and added Zn were tested. In addition to dietary treatment, the effects of gender and bakery by-product (barrow, gilt, or mixed gender) were included as fixed effects in the model. Hot carcass weight was used as a covariate for analyses of backfat thickness, loin depth, and percentage lean. Statistical significance was claimed at $P < 0.05$ and trends at $P < 0.10$.

Results and Discussion

From d 75 to 84, a bakery by-product × added Zn interaction ($P < 0.03$) occurred. Pigs fed diets with 50 ppm added Zn had a tendency for an increase (quadratic, $P < 0.1$) in ADG as dietary bakery by-product was increased from 0 to 7.5%, whereas pigs fed diets without 50 ppm added Zn had decreased ($P < 0.001$) ADG as dietary bakery by-product increased up to 15%. Although the interaction was significant for d 75 to 84, no interaction ($P > 0.15$) was observed for the overall period.

[7] NPPC 2001. Procedures for Estimating Pork Carcass Composition. Natl. Pork Prod. Counc., Des Moines, IA.
[8] NPPC 1999. Composition and Quality Assessment Procedures. Natl. Pork Prod. Counc., Des Moines, IA.

From d 75 to 84, pigs fed diets with 50 ppm added Zn from ZnO had decreased ($P < 0.03$) ADFI compared with the RAC control diet (Table 2); however, no differences ($P > 0.24$) occurred in ADG or F/G. From d 84 to 102, pigs fed diets containing 50 ppm added Zn had a tendency for increased ($P < 0.09$) ADG compared with those fed the RAC control diet. Overall (d 75 to 102), no differences ($P > 0.22$) in growth performance or carcass characteristics were observed when pigs were fed diets with 50 ppm added Zn compared with the RAC control (Table 3).

For pigs subsampled on d 84, pigs fed diets with 50 ppm added Zn had decreased ($P < 0.05$) belly edge thickness compared with those fed the RAC control (Table 4). For pigs subsampled on d 102, those fed diets with 50 ppm added Zn had decreased ($P < 0.02$) backfat thickness, belly weight, belly edge thickness, a tendency for decreased ($P < 0.07$) belly middle thickness, and increased ($P < 0.01$) percentage lean compared with pigs fed the RAC control.

Pigs fed RAC diets with 50 ppm added Zn tended to exhibit a 3% increase in ADG from d 84 to 102; however, the addition of 50 ppm Zn from ZnO did not improve overall performance. The increased growth rate during the d 84 to 102 period resulted in a numeric increase in IOFC of $0.47 per pig. Although the response to added Zn is not consistent, little improvement in performance is needed to cover the cost.

Table 1. Diet composition (as-fed basis)[1]

	No added Zn			50 ppm added Zn from ZnO		
Bakery, %	0	7.5	15	0	7.5	15
Ingredient,%						
Corn	63.25	56.28	49.22	63.24	56.27	49.21
Soybean meal (46.5% CP)	18.99	18.46	18.03	18.99	18.46	18.03
Bakery by-product	—	7.50	15.00	—	7.50	15.00
DDGS[2]	15.00	15.00	15.00	15.00	15.00	15.00
Choice white grease	0.70	0.70	0.70	0.70	0.70	0.70
Limestone	1.15	1.12	1.09	1.15	1.12	1.09
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin and trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
L-threonine	0.05	0.05	0.05	0.05	0.05	0.05
L-lysine[3]	0.40	0.43	0.45	0.40	0.43	0.45
Phytase[4]	0.007	0.007	0.007	0.007	0.007	0.007
Ractopamine HCl[5]	0.025	0.025	0.025	0.025	0.025	0.025
ZnO	—	—	—	0.007	0.007	0.007
Total	100	100	100	100	100	100
Zinc, ppm						
Calculated analysis						
Trace mineral premix	80	80	80	80	80	80
Added ZnO	0	0	0	50	50	50
Total	114	114	114	164	164	164
Analyzed values						
Total	103	109	124	150	190	148

[1] Dietary treatments were obtained by replacing corn in diets to achieve 50 ppm added Zn from zinc oxide (ZnO).
[2] DDGS: dried distillers grains with solubles.
[3] Biolys (50.7% L-Lys; Evonik Degussa Corporation, Kennesaw, GA).
[4] OptiPhos 2000 (Enzyvla LLC, Sheridan, NJ).
[5] Provided 9 g/lb Ractopamine HCl (Paylean, Elanco Animal Health, Greenfield, IN).

Table 2. Effects of added zinc on growth performance of finishing pigs fed Ractopamine HCl[1]

Item	Control	50 ppm added Zn	SEM	*P*<
d 75 to 84				
ADG, lb	2.47	2.40	0.04	0.24
ADFI, lb	6.81	6.60	0.07	0.03
F/G	2.77	2.76	0.04	0.77
IOFC, $/pig[2]	4.65	4.56	0.18	0.70
Caloric efficiency[3]				
ME	4,294	4,272	55	0.77
NE	3,148	3,131	40	0.77
d 84 to 102				
ADG, lb	2.30	2.37	0.03	0.09
ADFI, lb	6.72	6.79	0.06	0.41
F/G	2.93	2.87	0.03	0.21
IOFC, $/pig[2]	7.68	8.24	0.28	0.14
Caloric efficiency[3]				
ME	4,539	4,450	51	0.21
NE	3,329	3,263	38	0.20
d 75 to 102				
ADG, lb	2.36	2.38	0.02	0.55
ADFI, lb	6.75	6.72	0.05	0.61
F/G	2.86	2.82	0.02	0.23
IOFC, $/pig[2]	12.33	12.80	0.29	0.25
Caloric efficiency[3]				
ME	4,434	4,374	36	0.23
NE	3,251	3,206	27	0.22
Weight, lb				
d 75	224.8	224.4	1.6	0.85
d 84 (before tops)	247.1	246.0	1.7	0.63
d 84 (tops)	274.4	269.8	2.3	0.14
d 102	282.0	283.6	1.8	0.53
d 103[4]	280.9	282.5	1.8	0.55

[1] A total of 1,263 pigs (PIC 337 × 1050; initially 224.6 lb) were used in a 28-d study with 25 to 27 pigs per pen and 24 pens per treatment.

[2] IOFC: income over feed cost. Corn was valued at $220/ton, soybean meal at $400/ton, dried distillers grains with solubles at $210/ton, bakery by-product at $232/ton, Biolys at $0.70/lb, Optiphos 2000 at $2.65/lb, Ractopamine HCL at $35.26/lb, zinc oxide at $0.86/lb, and pig price at $0.61/lb.

[3] Expressed as kcal per pound of gain.

[4] Final BW collected at JBS Swift and Company (Worthington, MN) prior to harvest.

Table 3. Effects of added zinc on carcass characteristics of finishing pigs fed Ractopamine HCL[1]

Item	Control	50 ppm added Zn	SEM	$P<$
Weight, lb				
d 102	282.0	283.6	1.8	0.53
d 103[2]	280.9	282.5	1.8	0.55
Carcass characteristics				
HCW, lb	212.4	213.4	1.3	0.57
Farm yield, %[3]	75.31	75.24	0.22	0.83
Packing plant yield, %[4]	75.60	75.55	0.20	0.87
Backfat thickness, in.[5]	0.62	0.62	0.01	0.47
Loin depth, in.[5]	2.77	2.79	0.01	0.19
Lean, %[5,6]	54.00	54.15	0.11	0.32

[1] 1,263 pigs (PIC 337 × 1050; initially 224.6 lb) were used in a 28-d study with 25 to 27 pigs per pen and 24 pens per treatment.
[2] Final BW collected at JBS Swift and Company (Worthington, MN) prior to harvest.
[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[4] Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant prior to harvest.
[5] Adjusted using HCW as a covariate.
[6] Calculated using NPPC (2001) equation: (15.31 + 0.51 × (HCW, lb)-31.277 × (last rib backfat thickness,in.) + 3.813 × (loin muscle depth, in.)) / HCW × 100.

Table 4. Effects of added zinc on carcass quality of finishing pigs fed Ractopamine HCL[1]

Item	Control	50 ppm Zn	SEM	Probability $P<$
d 84[2]				
HCW	199.7	196.7	2.2	0.33
Backfat, in.[3]	0.68	0.65	0.03	0.53
Loin depth, in.[3]	2.33	2.32	0.05	0.88
Lean, %[3,4]	52.52	52.92	0.50	0.59
Kill floor pH	6.58	6.57	0.06	0.93
4-h pH	6.58	6.63	0.04	0.40
Belly trait				
Temperature, °F	33.3	32.9	0.6	0.67
Weight	15.03	14.79	0.28	0.55
Thickness middle, in.	0.91	0.90	0.02	0.81
Thickness edged, in.	1.14	1.05	0.03	0.05
Firmness[5]	2.61	2.66	0.09	0.68
Fat iodine value (IV)	79.21	79.12	0.51	0.90
Loin ph	5.86	5.86	0.02	0.82
Loin color[6]	3.43	3.55	0.10	0.39
Marbling[7]	1.55	1.60	0.08	0.67

continued

Table 4. Effects of added zinc on carcass quality of finishing pigs fed Ractopamine HCL[1]

Item	Control	50 ppm Zn	SEM	Probability $P<$
d 102[8]				
HCW	208.1	207.4	2.6	0.86
Backfat, in.[3]	0.65	0.58	0.02	0.01
Loin depth, in.[3]	2.80	2.84	0.05	0.50
Lean, %[3,4]	53.65	54.89	0.32	0.01
Kill floor pH	6.56	6.51	0.07	0.65
4-h pH	6.54	6.47	0.04	0.23
Belly trait				
Temperature, °F	32.7	31.8	0.6	0.22
Weight	16.55	15.64	0.27	0.02
Thickness middle, in.	1.08	1.02	0.03	0.07
Thickness edged, in.	1.19	1.11	0.03	0.02
Firmness[5]	1.89	2.11	0.11	0.16
Fat IV	77.32	77.56	0.81	0.83
Loin pH	5.80	5.81	0.02	0.93
Loin color[6]	3.41	3.34	0.14	0.75
Marbling[7]	1.63	1.45	0.11	0.22

[1]A total of 1263 pigs (PIC 337 × 1050; initially 77.8 lb) were used in 102-d study with 25 to 27 pigs per pen and 16 pens per treatment. There were 14 barrow pens, 11 gilt pens, and 23 mixed-sex pens.

[2] Five pigs per pen were sold as tops on d 84 of the experiment. The middle-weight pig was subsampled for collection of carcass quality measurements.

[3]Adjusted using HCW as a covariate.

[4]Calculated using NPPC (2001) equation: (15.31 + 0.51 × (HCW, lb) - 31.277 × (last rib backfat thickness, in.) + 3.813 × (loin muscle depth, in.)) / HCW

[5]Scored on scale: 1 = none to very little bend, 2 = moderate or 50% bend, 3 = belly ends touched.

[6]Scored on scale from 1 to 6, with 1 = pale and 6 = dark.

[7]Scored on scale from 1 to 10, with 1 = very little to no intramuscular lipid content and 10 = extreme amounts.

[8]The middle-weight pig of the remaining pigs in the pen was subsample for collection of carcass quality measurements.

Evaluation of Feeding Budgeting Strategy or Complete Diet Blending on Finishing Pig Growth Performance and Carcass Characteristics

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Summary

A total of 252 mixed-sex pigs (PIC 327 × 1050; initial BW = 79.8 ± 0.9 lb BW) were used in a 95-d growth study to compare feed-budgeting strategies and complete diet blending for finishing pigs on growth performance, carcass characteristics, and economics. Feed was delivered to all pens of pigs using a computerized feed delivery system (FeedPro, Feedlogic Corp., Willmar, MN) that is capable of delivering and dispensing 2 separate diets. Four experimental treatments had 9 pens/treatment and 7 pigs/pen in a randomized complete block design. Dietary treatments included: (1) standard 4-phase (0.91, 0.77, 0.67, and 0.61% standardized ileal digestible [SID] lysine, respectively) complete feed program (Standard), (2) blending a high- and low-lysine complete diet to meet the estimated daily SID lysine requirement from d 0 to d 95 (Curve), (3) Treatment 1 diets with 20% greater feed budget allowance per phase (Over), and (4) Treatment 1 diets with 20% lower feed budget allowance per phase (Under). Diets were corn-soybean meal–based with no added fat. The standard diet was budgeted at 117, 138, 158, and 175 lb for Phases 1 through 4, respectively.

Overall (d 0 to 95), no differences ($P \geq 0.11$) were observed in ADG, ADFI, F/G, or final BW among pigs fed the budgeting strategy diets. Pigs phase-fed a standard phase-feeding program tended to have heavier ($P = 0.09$) HCW than pigs fed the Curve and tended to have ($P = 0.10$) greater percentage carcass yield than those fed the Curve or the Over diet. No differences ($P \geq 0.14$) were observed in percentage lean, fat depth, or loin depth. Pigs fed diets blended to a lysine curve had lower feed costs ($P < 0.004$) than all three phase-feeding treatments, but because of heavier HCW, pigs fed the standard feed budget had greater ($P = 0.05$) revenue per pig and tended to have greater ($P = 0.10$) income over feed cost (IOFC) under two separate diet and carcass price scenarios compared with pigs fed with the Curve, with pigs over- and under-budgeted remaining intermediate. Over- and under-budgeting situations in phase feeding programs had minimal impact on growth performance, carcass characteristics, and net returns; furthermore, feeding blended diets to a lysine curve did not improve growth performance and led to lower total revenue than using a standard feed budget.

Key words: feed blending, feed budgeting, finishing pig, phase-feeding

Introduction

Pig growth and efficiency is maximized and nutrient excretion is reduced when pigs are fed diets that match their nutrient requirements. Generally, the optimal concentration of nutrients required by growing pigs decreases over the growing-finishing period, and

[1] Appreciation is expressed to Feedlogic Corp. for financial support to this study.

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phase feeding helps producers adjust to these requirements. In commercial production, phase feeding commonly involves feeding a series of 2 to 5 diets, each differing in energy or amino acid concentrations to match pig nutrient requirements at each weight phase. Delivering multiple phases to more precisely meet changes in nutrient requirements has been shown to have economic and environmental benefits (Van der Peet Schwering et al., 1999[3]); however, these advantages may be offset by the logistical difficulties and cost of additional feed storage, labor, and management. Currently, many production systems find it challenging to accurately estimate feed intake in each phase, which can result in delivering nutrient concentrations above or below pig requirements at different stages of the finishing period. In the case of underfed budgets, pig growth may become limited. In the case of overfeeding budgets, increased feed costs and excess nutrient excretion can occur. Both of these situations can negatively affect the net return of swine operations.

Blend feeding, which involves mixing of 2 base diets in proportionate ratios, can potentially increase the number of phases delivered throughout the finishing period. This feeding strategy has recently become a practical alternative to phase feeding with the development of automatic feeding systems such as the FeedPro system. Although previous studies comparing diet blending to phase feeding have shown conflicting results on growth performance, feed cost per pig has decreased consistently (Moore and Mullan, 2009[4]; Frobose et al., 2010[5]).

The objective of this study was to compare feed budgets or delivery systems in which blending 2 base complete diets using the FeedPro system was compared with a phase feeding program with a standard budget or over- and under-budgeted phase feeding programs to determine their effects on growth performance, carcass characteristics, and economics.

Procedures

All procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 252 pigs (PIC 327 × 1050; initially 79.8 ± 0.9 lb BW) were allotted to 1 of 4 experimental treatments using a randomized complete block design. Each treatment had 9 replicate pens and 7 pigs per pen (4 gilts and 3 barrows per pen). The experiment was conducted at the K-State Swine Teaching and Research Center growing-finishing facility. Each pen was 8 ft × 10 ft with adjustable gates facing the alleyway, allowing for continuous provision of 11.4 ft^2 per pig. Pens were equipped with a dry, single-sided self-feeder (Farmweld, Teutopolis, IL) with 2 feeding spaces located in the fence line. The facility also had the FeedPro system, an integrated feed dispensing system, and 12 feed storage bins.

The 4 experimental treatments were: (1) a standard 4-phase complete feed program (Standard), (2) blending a high- and low-lysine complete diet over the entire experi-

[3] Van der Peet Schwering, C. M. C. et al. 1999. Nitrogen and phosphorus consumption, utilization, and losses in pig production: The Netherlands. Livest. Prod. Sci. 58:213–224.

[4] Moore, K., and B. Mullan. 2009. Evaluation of feeding strategies and measurement of feed consumption using the Feedlogic system: Final report. Cooperative Research Centre for an Internationally Competitive Pork Industry, Department of Agriculture and Food, Australia. http://www.porkcrc.com.au/2A-104_Final_Report_0902.pdf. Accessed November 25, 2009.

[5] Frobose et al., Swine Day 2010. Report of Progress 1038, pp. 242–252.

ment (Curve), (3) Treatment 1 diets with 20% greater feed allowance per phase (Over), and (4) Treatment 1 diets with 20% lower feed allowance per phase (Under). All diets were dispensed using the FeedPro system and provided ad libitum access to feed. For the standard 4-phase feeding program as well as the Over and Under treatments, 4 finishing diets (Table 1) were formulated to provide 0.91, 0.77, 0.67, and 0.61% SID lysine corresponding to 2.72, 2.30, 2.00, and 1.81 g SID lys/Mcal ME.

The FeedPro system was programmed to deliver a predetermined amount of feed from each diet to each pen and to automatically update allotted budgets when pigs were removed due to death or illness. Pigs fed the standard treatment were programmed to receive a set feed budget of 117, 138, 158, and 175 lb per pig for Phases 1 to 4, respectively. Pigs fed the Over and Under treatments were assigned feed allowances of 20% higher and 20% lower than their standard counterparts. Phase changes in the Over and Under treatments took place when allotted feed budgets were exhausted on an individual pen basis. Accordingly, the date of phase change in the Over and Under treatments was based on the time when half of the pens within the treatment had automatically switched phases.

For the Curve treatment, a complete high-lysine and low-lysine diet (Table 1) was formulated to provide 0.99 and 0.59% SID lysine (2.97 and 1.75 g SID lys/Mcal ME), respectively. The two diets were blended in varying proportions on a daily basis (Figure 1) to meet a SID lysine estimate curve that was set using previously documented feed intake data for pigs in this facility. The SID lys:ME ratios (g/Mcal) provided by the 4 feeding programs to pigs throughout the finishing period are shown in Figure 2. The figure illustrates the stair-step reduction of lysine:calorie ratios used for the different phase feeding treatments and the more gradual reduction in lysine:calorie ratio for the diet blending treatment. The gradual reduction in the lysine:calorie ratio was achieved by changing the ratio of the two diets provided on a daily basis. All complete diets, ground corn, and supplements were manufactured at the K-State Animal Science Feed Mill. Feed samples were collected after diet manufacturing, homogenized, and analyzed for lysine content at the University of Missouri Agricultural Experiment Station Chemical Laboratories.

Pigs from all treatments were weighed and feed disappearance was recorded on the date of phase changes for the standard treatment to establish equal periods for data comparison. Average daily gain, ADFI, and F/G were calculated from the records collected at each of these phase changes. The data periods were d 0 to 23 (Phase 1), d 23 to 49 (Phase 2), d 49 to 72 (Phase 3), and d 72 to 95 (Phase 4).

On d 95, pigs were weighed and transported (approximately 160 miles) to an abattoir (Triumph Foods, Inc., St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage carcass yield, backfat, and loin depth. Percentage carcass yield was calculated by dividing HCW by live weight obtained at the farm before transport to the abattoir. Fat depth and loin depth were measured with an optical probe (SFK, Herlev, Denmark) inserted between the 3rd and 4th ribs located anterior to the last rib at a distance approximately 2.8 in. from the dorsal midline. Fat-free lean index

(FFLI) was calculated using NPPC (2000[6]) guidelines for carcasses measured with the Fat-O-Meater such that FFLI = ((15.31 + (0.51 × HCW, lb) – (31.277 × last rib fat thickness, in.) + (3.813 × loin muscle depth, in.))/HCW, lb. Grade premiums and sort loss discounts were also included to accurately determine the net revenue generated per pig.

Feed cost was calculated as the sum of diet cost and grind, mix, and delivery (GMD) costs. The individual components of the GMD charges used were (1) grinding = $3.50/ton, (2) mixing = $2.50/ton, and (3) delivery = $6/ton. The complete diets used in all treatments received all three charges (grinding, mixing, and delivery). Feed cost per pig and feed cost per pound of of gain were calculated for each phase and overall according to 2 diet cost scenarios based on July 2010 and October 2011 prices. Total revenue and IOFC were also determined under 2 scenarios (carcass base prices of $72.09 and $87.37/cwt for Scenario 1 and 2, respectively).

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC), with pen as the experimental unit and location in the barn as the blocking factor. Hot carcass weight was used as a covariate for fat depth, loin depth, lean percentage, and FFLI. When treatment effect was a significant source of variation, means were separated using CONTRAST statements in SAS. Least square means were calculated for each independent variable. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$ for all statistical tests.

Results and Discussion

Dietary lysine levels are in general agreement with formulated lysine content (Table 2). Although pen weights and feed disappearance were recorded on d 23, 49, 72, and 95 according to average phase changes in the standard treatment, in the Over treatment, the average dates of diet changes were d 29, 56, and 83 for Phases 2 through 4, respectively. In the Under treatment, the average dates of diet changes were d 18, 42, and 61 for Phases 2 through 4, respectively.

In Phase 1 (d 0 to 23), ADG was lower ($P < 0.04$) in pigs fed the Curve treatment compared with each of the three phase-fed programs (Table 3). Although no differences ($P > 0.47$) in ADFI were observed across treatments, pigs fed the curve program had poorer ($P < 0.04$) F/G than pigs fed over- and under-budgeted phase feeding programs. Although ADG was similar ($P > 0.16$) across all treatments during Phase 2 (d 23 to 49), under-budgeted pigs had greater ADFI ($P < 0.05$) than Curve pigs and poorer F/G ($P < 0.05$) than pigs fed Standard or Curve programs. In Phase 3 (d 49 to 72), pigs in the Standard and Under programs had greater ($P < 0.05$) ADG than pigs fed the Over program, with Curve fed pigs intermediate. Feed intake was similar ($P > 0.18$) across treatments in Phase 3, but pigs fed the Under program had improved ($P < 0.05$) F/G when compared with pigs that were over-budgeted for each phase. In Phase 4 (d 72 to 95), no differences ($P > 0.13$) were observed in ADG, ADFI, or F/G across treatments. Overall (d 0 to 95), no differences ($P > 0.11$) occurred in ADG, ADFI, F/G, or final BW across budgeting programs.

[6] NPPC. 1991. Procedures to evaluate market hogs. Third ed. National Pork Producers Council. Des Moines, IA.

These results agree with Sulabo et al. (2010[7]), who evaluated growth performance of finishing pigs fed a standard phase feeding program or blended diets using the FeedPro system. Moore and Mullan (2009[8]) also compared a conventional 3-phase feeding program from 50 to 195 lb to a 2-diet blend fed in weekly phases using a similar Feedlogic system and found no differences in growth performance; however, a more recent study (Frobose et al., 2010[9]) conducted in a commercial environment found an advantage in ADG for pigs fed a standard 4-phase program over those fed blended diets using the FeedPro system.

For carcass characteristics, there was a trend ($P = 0.09$) for pigs fed the Standard program to have greater carcass yield than pigs fed the Over or Curve diets (Table 4). This result was driven by a trend ($P = 0.10$) for heavier HCW in pigs fed the Standard program compared with Curve. Across treatments, no differences ($P > 0.14$) were observed in percentage lean, fat depth, or loin depth. These results were similar to previous research (Frobose et al., 2011; Sulabo et al., 2011) that showed numerical advantages in HCW for phase-fed pigs over those fed diets blended to a lysine curve.

Feeding diets blended to a lysine curve resulted in the lowest ($P < 0.03$) feed costs in phases 2, 3, and overall, resulting in average feed savings/pig of $4.09 over the three phase-fed strategies (Table 5). For feed cost per pound of gain, feeding Curve diets resulted in greater ($P < 0.03$) costs compared with pigs fed Over diets during Phase 1, with Standard and Under treatments intermediate. Conversely, in Phase 2, curve diets resulted in the most economical weight gain ($P < 0.001$), and in Phase 3, pigs fed Curve and Under programs had lower ($P < 0.04$) feed cost per pound of gain than those fed Over diets. Overall, delivering diets to a lysine curve resulted in lower ($P < 0.01$) cost per pound of gain than over-budgeting and tended ($P < 0.06$) to be lower than standard and under treatments. Total revenue received per pig tended ($P < 0.10$) to be greater ($5.37/pig) for pigs fed Standard diets over Curve or Under programs, which was mainly due to the advantage in ADG in standard pigs, which resulted in heavier HCW. Pigs phase-fed a correctly estimated feed budget (standard) tended ($P < 0.09$) to have greater IOFC than Curve ($4.61/pig) or Over ($4.55/pig) treatments, whereas pigs fed under-budgeted diets performed similarly ($P > 0.49$) to their Standard phase-fed counterparts, giving up just $1.81 per pig.

Blending 2 complete diets to a lysine curve did not significantly affect growth performance compared with the standard 4-phase feeding program. The numerically lower feed costs in the Curve over Standard treatment agree with previous research by Frobose et al. (2010) and Sulabo et al. (2010[10]), who saw feed cost savings of $2.32 and $1.92, respectively. In contrast to previous research, however, these feed savings did not result in an advantage in IOFC in either cost scenario, which was negatively affected by reduced growth performance in the initial phase of the trial for the curve treatment and higher total revenue/pig in each the three phase-feeding treatments.

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[7] Sulabo et al., Swine Day 2010, Report of Progress 1038, pp. 232.
[8] Moore, K., and B. Mullan. 2009. Evaluation of feeding strategies and measurement of feed consumption using the Feedlogic system: Final report. Cooperative Research Centre for an Internationally Competitive Pork Industry, Department of Agriculture and Food, Australia. http://www.porkcrc.com.au/2A-104_Final_Report_0902.pdf.
[9] Frobose et al., Swine Day 2010, Report of Progress 1038, pp. 242–252
[10] Sulabo et al., Swine Day 2010, Report of Progress 1038, pp. 232–241.

Over-budgeted diets may result in restricted growth in the mid- and late-finishing periods due to an oversupply of protein. This agrees with Lee et al. (2000[11]), who showed that excess amino acids that cannot be used for body protein deposition must be deaminated and excreted, resulting in a deterioration of growth and feed efficiency. Conversely, under-budgeted diets appeared to supply a SID lysine:ME ratio slightly below biological requirements during the initial phases of the experiment. Growth performance for under-budgeted pigs was slightly poorer during Phases 1 and 2 (d 0 to 49), but similar to standard pigs in late finishing (d 49 to 95). Based on well-documented compensatory growth responses seen when feeding adequate protein in later growth periods, Main et al. (2008[12]) suggested that as long as lysine requirements are met in late-finishing, feeding slightly less than the lysine requirement in early finishing may offer feed cost savings without forfeiting growth performance. Likewise, in the current study, under-budgeting by 20% appears to result in similar growth performance responses and potential feed cost reductions.

This study indicates that over- and under-budgeting during finishing have minimal impact on net returns, but as additional efforts are made to minimize feed costs in the finishing phase, formulating early finishing diets slightly lower than the pigs' physiological needs may offer an opportunity for feed savings. Furthermore, diet blending appears to offer small improvements in total feed costs, albeit with minor reductions in growth performance. Producers should consider this along with the impact on management, labor, and feed storage space associated with blending diets compared with phase feeding.

[11] Lee, J. H., J. D. Kim, J. H. Kim, J. Jin, and I. K. Han. 2000. Effect of phase feeding on the growth performance, nutrient utilization and carcass characteristics in finishing pigs. Asian-Aus. J. Anim. Sci. 13:1137–1148.

[12] Main, R. G., S. S. Dritz, M. D. Tokach, R. D. Goodband, J. L. Nelssen, and J. M. DeRouchey. 2008. Effects of feeding growing pigs less or more than their lysine requirement in early and late finishing on overall performance. Prof. Anim. Sci. 24:76–87.

Table 1. Diet composition for the phase-feeding and diet-blending treatments (as-fed basis)

	Standard[1]				Curve[2]	
Item	Phase 1	Phase 2	Phase 3	Phase 4	High lysine	Low lysine
Ingredient, %						
Corn	78.42	83.10	86.46	88.45	75.80	89.11
Soybean meal, 46.5% CP	18.95	14.60	11.48	9.63	21.44	8.99
Monocalcium phosphate, 21% P	0.50	0.30	0.23	0.15	0.55	0.13
Limestone	0.95	0.95	0.90	0.90	0.96	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.13	0.10	0.08	0.16	0.07
Trace mineral premix	0.15	0.13	0.10	0.08	0.16	0.07
L-lysine HCL	0.30	0.26	0.23	0.22	0.32	0.21
DL-methionine	0.03	---	---	---	0.04	---
L-threonine	0.07	0.04	0.03	0.04	0.09	0.04
Phytase[3]	0.13	0.13	0.13	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lysine	0.91	0.77	0.67	0.61	0.99	0.59
Isoleucine:lysine	61	63	64	66	60	66
Methionine:lysine	29	28	30	32	29	32
Met & Cys:lysine	56	58	62	66	55	67
Threonine:lysine	62	62	63	66	62	66
Tryptophan:lysine	16.5	16.5	16.5	16.5	16.5	16.5
Valine:lysine	71	74	78	81	69	82
Total lysine, %	1.01	0.86	0.75	0.69	1.10	0.67
ME, kcal/lb	1,515	1,519	1,522	1,525	1,513	1,525
SID lysine:ME, g/Mcal	2.72	2.30	2.00	1.81	2.97	1.75
CP (N × 6.25)	15.80	14.10	12.90	12.20	16.80	12.00
Ca, %	0.54	0.49	0.45	0.43	0.56	0.43
P, %	0.46	0.40	0.37	0.35	0.48	0.34
Available P, %	0.28	0.23	0.21	0.19	0.29	0.19
Diet cost/ton, U.S. $[4]	258.52	249.97	245.06	242.02	263.16	240.88

[1] Phases 1, 2, 3, and 4 were fed in the standard program from d 0 to 23, d 23 to 49, d 49 to 76, and d 76 to 109, respectively. Over and Under programs underwent phase changes automatically when allotted budget was consumed.
[2] Feed delivery based on a lysine estimate curve where a complete high- and low-lysine diet was blended throughout the duration of the experiment.
[3] Phyzyme 2500 (Danisco Animal Nutrition, St. Louis, MO).
[4] Diet costs were calculated with $5.93/bu corn and $355.51/ton soybean meal.

Table 2. Analyzed dietary lysine (as-fed basis)[1]

Diet	Total lysine, %
Phase feeding[2]	
Phase 1	0.98
Phase 2	0.84
Phase 3	0.72
Phase 4	0.69
Feed blending[3]	
High-lysine	1.03
Low-lysine	0.64

[1] Diet samples collected after manufacturing. Samples were analyzed for total lysine at the University of Missouri Experiment Station Chemical Laboratories (Columbia, MO).
[2] Phases 1, 2, 3, and 4 were fed to the standard phase feeding program from d 0 to 23 (117 lb), d 23 to 49 (138 lb), d 49 to 72 (160 lb), and d 72 to 95 (175 lb), respectively. Over and Under treatments underwent phase changes automatically when allotted budget (20% over and 20% under) the standard feed allowances were consumed.
[3] Feed delivery based on a lysine requirement curve where a complete high- and low-lysine diet was blended for the duration of the experiment.

Table 3. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- and under-budgeting in a phase feeding program on finishing pig growth performance[1]

	Feed budgeting program				
Item	Standard	Curve	Over	Under	SEM
Pig weights, lb					
Initial	79.8	79.8	79.8	79.8	0.87
d 23	130.0	128.4	130.4	130.0	1.23
d 49	186.6	184.2	185.2	185.4	1.84
d 72	241.6	237.6	239.8	239.7	2.45
d 95	292.8	289.0	290.5	291.0	2.89
Phase 1 (d 0 to 23)					
ADG, lb	2.19^{b}	2.11^{a}	2.20^{b}	2.18^{b}	0.026
ADFI, lb	4.67	4.61	4.64	4.63	0.061
F/G	2.13^{x}	$2.19^{b,y}$	2.11^{a}	2.12^{a}	0.022
Phase 2 (d 23 to 49)					
ADG, lb	2.18	2.10	2.11	2.13	0.040
ADFI, lb	5.63^{y}	5.34^{ax}	5.48^{ab}	5.68^{b}	0.113
F/G	2.59^{a}	2.55^{a}	2.60^{ab}	2.67^{b}	0.026
Phase 3 (d 49 to 72)					
ADG, lb	2.39^{b}	2.32^{ab}	2.23^{a}	2.36^{b}	0.046
ADFI, lb	6.56	6.48	6.41	6.37	0.098
F/G	2.75^{ab}	2.79^{ab}	2.91^{b}	2.70^{a}	0.072
Phase 4 (d 72 to 95)					
ADG, lb	2.23	2.23	2.20	2.23	0.044
ADFI, lb	7.22	7.38	7.11	7.22	0.121
F/G	3.25	3.31	3.23	3.23	0.057
Overall (d 0 to 95)					
ADG, lb	2.25	2.18	2.18	2.22	0.027
ADFI, lb	6.01	5.92	5.88	5.97	0.082
F/G	2.68	2.71	2.70	2.68	0.027

[a,b x,y] Within a row, means without a common superscript differ at $P < 0.05$ for statistical significance and $P < 0.10$ for trends.

[1] A total of 252 pigs (initially 79.8 ± 0.9 lb BW) were used with 9 replicate pens per treatment and 7 pigs per pen.

[2] Standard = complete diets in each phase; Curve = blending of high- and low-lysine diet fed to a set lysine curve; Over = Phase feeding diets with 20% greater feed allowance per phase; Under = Phase feeding with 20% lower feed allowance per phase.

Table 4. Effects of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- and under-budgeting in a phase feeding program on carcass characteristics of finishing pigs[1]

	Feed budgeting program[2]				
Item	Standard	Curve	Over	Under	SEM
HCW, lb	219.9[y]	215.1[x]	215.9[xy]	217.1[xy]	2.14
Carcass yield, %	75.1[y]	74.5[x]	74.4[x]	74.6[xy]	0.24
Lean, %[3,4]	25.8	24.9	24.6	25.4	0.52
Fat depth, in.[3]	1.01	0.98	0.97	1.00	0.020
Loin depth, in.[3]	2.33	2.29	2.34	2.31	0.041

[1] Carcass data from 252 mixed-sex pigs.
[2] Standard = complete diets in each phase; Curve = blending of high- and low-lysine diet fed to a set lysine curve; Over = Phase feeding diets with 20% greater feed allowance per phase; Under = Phase feeding with 20% lower feed allowance per phase.
[3] Adjusted with HCW as covariate.
[4] Calculated using NPPC (1991) guidelines for lean containing 5% fat. Lean % = (2.83 + (0.469 × HCW) − (18.47 × Fat depth) + (9.824 × Loin depth)/ (HCW).
[a,b x,y] Within a row, means without a common superscript differ at $P < 0.05$ for statistical significance and $P < 0.10$ for trends.

Table 5. Economics of diet blending using the FeedPro system (Feedlogic Corp., Willmar, MN) and over- or under-budgeting in a phase feeding program on finishing pig performance[1]

	Feed budget program[2]				
Item	Standard	Curve	Over	Under	SEM
Feed cost/pig, $					
Phase 1	15.90	15.57	15.76	15.81	0.189
Phase 2	20.79[b]	18.46[a]	20.32[b]	20.54[b]	0.405
Phase 3	24.27[b]	22.91[a]	24.15[b]	23.80[ab]	0.386
Phase 4	24.62	24.09	24.73	24.67	0.355
Total	85.59[b]	81.03[a]	84.95[b]	84.82[b]	0.949
Feed cost/lb gain, $[3]					
Phase 1	0.303[ab]	0.309[b]	0.300[a]	0.303[ab]	0.003
Phase 2	0.353[b]	0.326[a]	0.356[b]	0.357[b]	0.004
Phase 3	0.425[ab,x]	0.413[a,x]	0.456[b,y]	0.421[a,x]	0.012
Phase 4	0.464	0.452	0.470	0.462	0.008
Total	0.386[ab,y]	0.375[a,x]	0.393[b,y]	0.386[ab,y]	0.004
Total revenue, $/pig[4]	192.87[y]	187.24[x]	187.75[x]	190.32[xy]	2.161
IOFC[5]	111.98[y]	107.37[x]	107.43[x]	110.17[xy]	1.953

[a,b x,y] Within a row, means without a common superscript differ $P < 0.05$ for statistical significance and $P < 0.10$ for trends.
[1] Data collected from 252 pigs (approximately 63 pigs per treatment).
[2] Standard = complete diets in each phase; Curve = blending of high- and low-lysine diet fed to a set lysine curve; Over = Phase feeding diets with 20% greater feed allowance per phase; Under = Phase feeding with 20% lower feed allowance per phase.
[3] Feed cost/lb gain = (direct feed cost + grinding, mixing, and delivery [GMD] cost/pig) ÷ total live gain; assumed grinding = $5/ton; mixing = $3/ton; delivery and handling = $7/ton.
[4] Total revenue = carcass base price (($90.27/cwt; includes premiums/discounts for lean and yield) × HCW)/100.
[5] Income over feed cost = total revenue/pig − feed cost/pig.

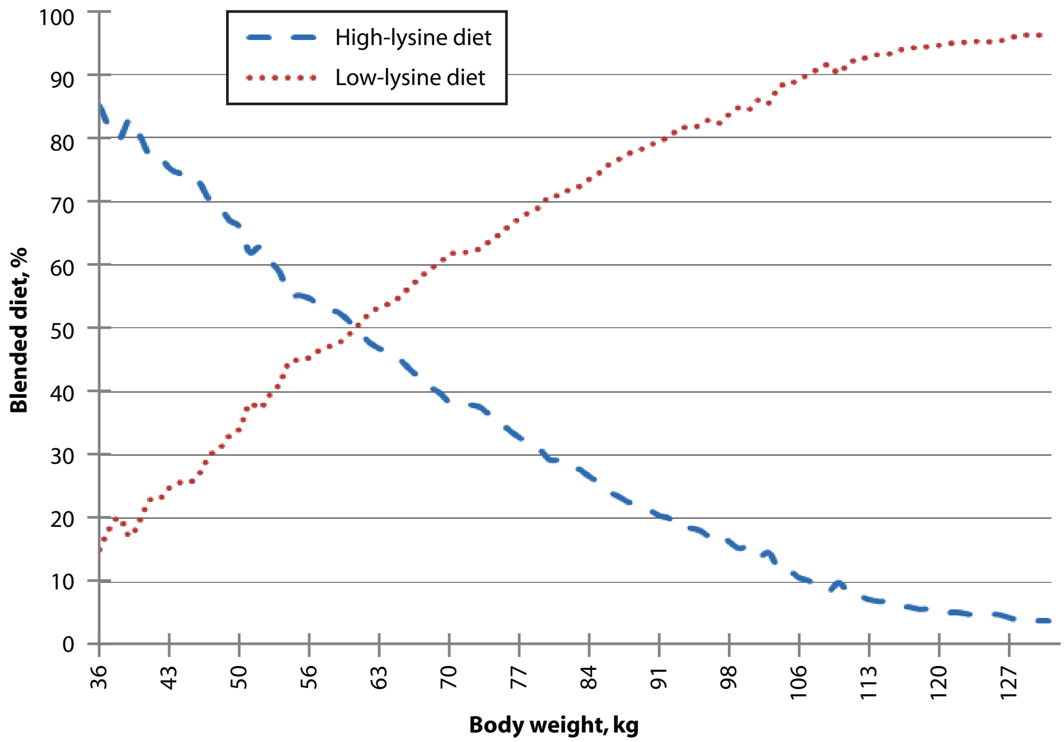

Figure 1. Percentage of the high- and low-lysine diets blended to a set lysine requirement curve using the FeedPro system (Feedlogic Corp., Willmar, MN).

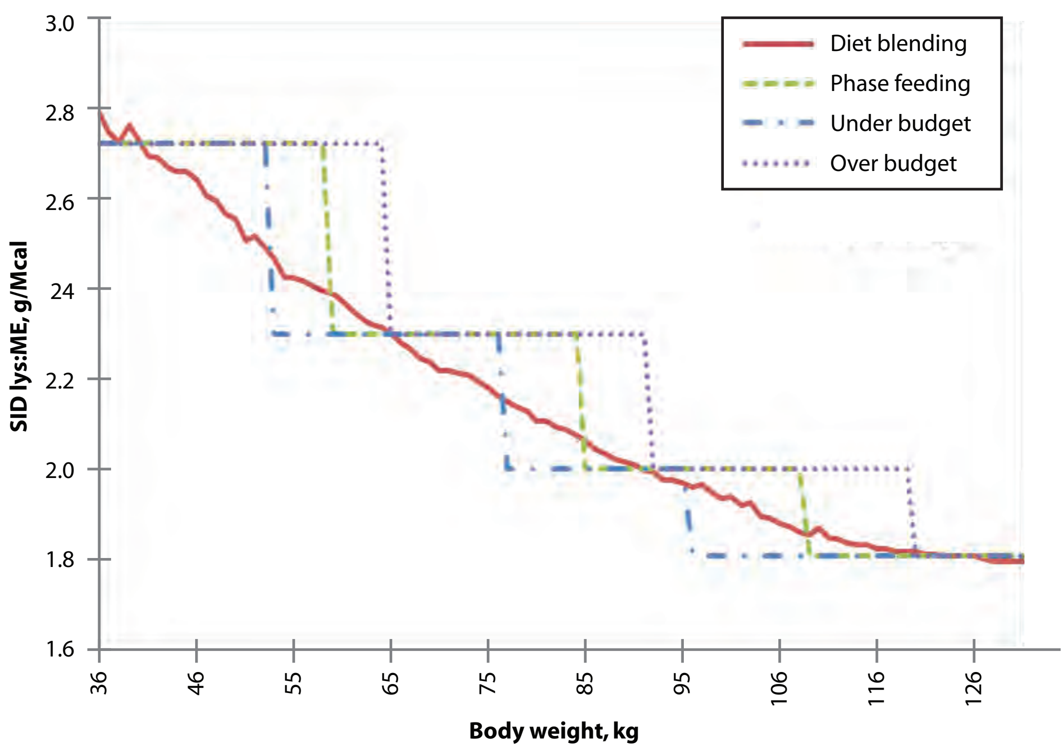

Figure 2. Standardized ileal digestible lys:ME ratio (g/Mcal) delivered to pigs (80 to 291 lb BW) based on a 4-phase feeding program with 3 different feed budgeting strategies compared with blending of high- and low-lysine diets based on a predetermined lysine curve using the FeedPro system (Feedlogic Corp., Willmar, MN).

Effects of Feeder Design (Conventional Dry vs. Wet-Dry) on Growth Performance of 45- to 246-lb pigs[1]

S. Nitikanchana[2], S. S. Dritz[2], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

A total of 1,253 pigs (PIC 1050 × 337; initially 45 lb) were used in a 104-d study to evaluate the effects of using a wet-dry (WD) or conventional dry (CD) feeder on growth performance of growing-finishing pigs. At the start of the trial, pens of pigs were weighed and randomly allotted to 1 of the 2 feeder types. The CD feeder was a single-sided, 56-in.-wide, stainless steel feeder (Thorp Equipment, Inc., Thorp, WI) with 4 14-in. feeding spaces and a 4.25-in.-deep trough. A cup waterer in pens using CD feeders ensured ad libitum access to water as well as feed. The WD feeder was double-sided (15-in.-wide feeder opening on each side) with a single nipple waterer (Crystal Springs, GroMaster, Inc., Omaha, NE), and the feeder was the only source of water. All pigs were fed the same corn-soybean meal diets containing 30% bakery by-product and 10 to 45% dried distillers grains with solubles (DDGS) during 5 dietary phases. For the overall period, pigs fed with the WD feeder had greater ADG ($P < 0.01$) and ADFI ($P = 0.01$) with no differences in F/G ($P = 0.50$) compared with pigs fed using the CD feeder. This study confirms previous results where pigs fed using a WD feeder have greater ADG and ADFI than those fed with a CD feeder.

Key words: conventional dry feeder, wet-dry feeder, finishing pig

Introduction

Recent studies have demonstrated that finishing pigs fed using WD feeders had improved weight gain, feed intake, and final BW; however, F/G responses were inconsistent among trials. Last year, Nitikanchana et al. (2011[3]) observed improved ADG and F/G in pigs fed using a WD feeder. This result was in contrast to studies in the same facility where poorer or no difference was observed in F/G for pigs fed with a WD compared to a CD feeder[4,5]; therefore, this trial was conducted to validate the response of WD feeder on growth performance and to obtain further data to use in a meta-analysis comparing growth performance and carcass characteristics of pigs fed with CD and WD feeders.

[1] Appreciation is expressed to New Horizon Farms for use of pigs and facilities and to Richard Brobjorg, Scott Heidebrink, and Marty Heintz for technical assistance.

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[3] Nitikanchana et al., Swine Day 2011, Report of Progress 1038, pp. 257–261.

[4] Bergstorm, J.R. 2011. The effect of feeder design, dietary level of dried distillers' grain with solubles, and gender on the performances and carcass characteristics of finishing pigs. College of Agriculture, Kansas State University. Dissertation.

[5] Myers, A.J. 2011. Effect of diet form and feeder design on growth performance of finishing pigs. College of Agriculture, Kansas State University. Thesis.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing barn in southwestern Minnesota. The barns were naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits for manure storage. Twenty-four pens were equipped with a single-sided, 56-in.-wide, conventional dry stainless steel feeders (Thorp Equipment, Inc., Thorp, WI; Figure 1) with 4 14-in feeding spaces and a 4.25-in.-deep trough. A cup waterer in pen using CD feeder ensured ad libitum access to water as well as feed. The remaining 24 pens were equipped with double-sided, stainless steel WD feeders (Crystal Springs, GroMaster, Inc., Omaha, NE; Figure 2) with a 15-in.-wide feeder opening on both sides and a single nipple waterer to provide water. Feeder opening was adjusted throughout the study to accommodate the flowability of feed and to provide unrestricted access to feed with little wastage for both feeder types. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 1,253 pigs (PIC 1050 × 337) with an initial BW of 45 lb were used in a 104-d study. Pens contained 25 to 27 pigs with equal number of barrows and gilts. At the start of the trial, pens of pigs were weighed and randomly allotted to 1 of the 2 feeder types. All pigs were fed the same corn-soybean meal diets containing 30% bakery by-product and 10 to 45% DDGS during 5 dietary phases from 45 to 70 lb , 70 to 123 lb, 123 to 180 lb, 180 to 205 lb, and 205 to 246 lb (Table 1). Pens of pigs were weighed and feed disappearance was recorded at d 15, 43, 71, 83, and 104 to determine ADG, ADFI, and F/G. The experimental data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for all data and significance and tendencies were set at $P < 0.05$ and $P < 0.10$, respectively.

Results and discussion

For the overall period, pigs fed with the WD feeders had 3% greater ADG ($P < 0.01$; Table 2) and 4% greater ADFI ($P = 0.01$) than pigs fed with the CD feeders. No differences were observed in F/G ($P = 0.50$) among pigs fed with the WD vs. CD feeder. The improvement in ADG confirms previous results, where pigs fed with a WD feeder had greater ADG than those fed with a CD feeder (Bergstrom, 2011[4]); however, in many of the previous studies, F/G responses varied widely among pigs fed with different feeder types. Many results show that pigs fed with WD feeders have poorer F/G than those fed with CD feeders (Bergstrom et al., 2011[4]). Recent results of a study conducted at the same facility (Nitikanchana et al., 2011[6]) found improved F/G in pigs fed with WD feeders. The variation in response to F/G among trials demonstrates the need for careful feeder management to ensure benefits in ADG are not offset by poorer F/G.

[6] Nitikanchana et al., Swine Day 2011, Report of Progress 1038, pp. 257–261.

Table 1. Diet composition (as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Ingredient, %					
Corn	17.30	10.38	15.63	37.06	46.76
Soybean meal (46.5% CP)	20.18	12.04	6.88	11.00	11.25
Bakery by-product	30.00	30.00	30.00	30.00	30.00
DDGS[2]	30.00	45.00	45.00	20.00	10.00
Monocalcium P, 21% P	0.05	---	---	---	0.21
Limestone	1.26	1.42	1.39	1.06	0.96
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.09
DL-methionine	---	---	---	---	---
L-threonine	0.035	---	---	---	---
L-lysine sulfate	0.725	0.710	0.650	0.425	0.370
Phytase[3]	0.005	0.005	0.005	0.005	0.005
Total	100	100	100	100	100
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.16	0.99	0.83	0.75	0.70
Isoleucine:lysine	66	71	74	74	72
Leucine:lysine	158	192	215	193	183
Methionine:lysine	29	35	38	35	34
Met & Cys:lysine	60	71	79	73	70
Threonine:lysine	61	65	69	66	64
Tryptophan:lysine	17.0	17.0	16.9	18.4	18.5
Valine:lysine	77	86	92	89	87
Total lysine, %	1.34	1.18	1.01	0.88	0.81
ME, kcal/lb	1,561	1,561	1,562	1,565	1,564
SID lysine:ME, g/Mcal	3.37	2.88	2.41	2.17	2.03
CP, %	22.8	22.5	20.5	17.3	15.4
Ca, %	0.61	0.63	0.61	0.50	0.50
P, %	0.49	0.51	0.49	0.40	0.40
Available P, %	0.30	0.35	0.35	0.22	0.22

[1] The 5 diets were fed from 45 to 70 lb, 70 to 123 lb, 123 to 180 lb, 180 to 205 lb, and 205 to 247 lb.
[2] DDGS: dried distillers grains with solubles from Valero (Aurora, SD).
[3] OptiPhos 2000 (Enzyvia LLC, Sheridan, IN).

Table 2. Effects of feeder design (conventional dry vs. wet-dry) in 45- to 246-lb pigs[1]

Feeder type	Conventional dry[2]	Wet-dry[3]	SEM	Probability, *P*<
d 0 to 104				
ADG, lb	1.90	1.96	0.01	0.01
ADF, lb	4.74	4.92	0.05	0.01
F/G	2.49	2.51	0.02	0.50
BW, lb				
d 0	45.0	45.0	0.87	0.98
d 104	243.4	249.9	1.69	0.01

[1] A total of 1,253 pigs (PIC 1050 × 337, initially 45 lb) were used in a 104-d growing-finishing trial with 25 to 27 pigs per pen and 24 pens per treatment.
[2] Conventional dry feeders (Thorp Equipment, Inc., Thorp, WI) were single-sided, 56-in.-wide, 4-hole stainless steel with a 4.25-in.-deep trough.
[3] A double-sided, stainless steel wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE) with a 15-in.-wide feeder opening on both sides.

Figure 1. Conventional dry feeder (Thorp Equipment, Inc., Thorp, WI).


Figure 2. Wet-dry feeder (Crystal Springs, GroMaster, Inc., Omaha, NE).

Meta-Analysis Comparing Growth Performance, Carcass Characteristics, and Water Usage of Growing-Finishing Pigs Fed Using Conventional Dry and Wet-Dry Feeders

S. Nitikanchana[1], S. S. Dritz[1], M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen

Summary

Fifteen trials were used for meta-analyses comparing the effects of conventional dry (CD) and wet-dry (WD) feeders on growth performance, carcass traits, and water usage of growing-finishing pigs. The meta-analysis indicated that pigs fed with WD feeders consistently had greater ($P < 0.01$) ADG (0.09 lb/d) and ADFI compared with those fed with CD feeders; however, although highly variable, no overall difference ($P = 0.93$) was observed in F/G. As a result of improved growth rate, final BW and HCW of pigs fed with WD feeders was 3.2% greater ($P < 0.01$) than when fed with CD feeders. For carcass traits, backfat was greater ($P < 0.01$) and percentage lean was lower ($P < 0.01$) in pigs fed with WD feeders compared with those fed with CD feeders. Carcass yield and loin depth did not differ ($P > 0.14$) among feeder types. Water usage for pigs fed with WD feeders was 0.4 gal/pig/d less ($P = 0.02$) than for pigs using CD feeders. Growing-finishing pigs fed with WD feeders had increased growth rate, feed intake, final BW, and HCW, but deposited more fat as indicated by greater backfat and lower percentage lean.

Key words: conventional dry feeder, wet-dry feeder, finishing pig, meta-analysis

Introduction

Recent studies have demonstrated that finishing pigs fed using WD feeders had improved ADG, ADFI, and final BW; however, F/G responses are inconsistent among trials. Nitikanchana et al. (2011[2]) observed improved F/G in pigs fed with WD feeders; in contrast, studies in the same facility indicated poorer or no difference in F/G in pigs fed with a WD compared with a CD feeder.[3,4]

Wet-dry feeders also influence carcass characteristics and water usage of finishing pigs. Myers et al. (2011[3]) and Bergstorm et al. (2011[4]) found a greater backfat and lower lean percentage in pigs fed with a WD feeder compared with a CD feeder, which can reduce carcass price and the economic benefits of using a WD feeder. The inconsistency of feed efficiency responses and impact of WD feeders on carcass traits are major factors to

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[3] Myers, A.J. 2011. Effect of diet form and feeder design on growth performance of finishing pigs. College of Agriculture, Kansas State University. Thesis.
[4] Bergstrom, J.R. 2011. The effect of feeder design, dietary level of dried distillers' grain with solubles, and gender on the performances and carcass characteristics of finishing pigs. College of Agriculture, Kansas State University. Dissertation.

consider when using WD feeders. Therefore, we conducted a meta-analysis of available studies to evaluate the influence of WD feeders on growth performance, carcass traits, and water usage of growing-finishing pigs.

Procedures

A comprehensive search via Kansas State University Libraries using the internet and the ISI Web of KnowledgeSM/CABI search engine was used to obtain published data including theses and university publications. The criteria for selection of data included experiments conducted with complete randomized design or randomized complete block design, replicated treatments, and a clear description or diagram of the WD feeder to confirm that the water source was indeed located within the feeder. The search resulted in 15 trials with growth performance data, 8 trials that measured carcass characteristics (carcass weight, backfat, loin depth, percentage carcass yield), 9 trials that reported lean percentage, 5 trials listing water disappearance, and 3 trials that included diet type (meal vs. pellet) in their comparison of feeder types. Data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Means for feeder type (CD and WD) within trial and diet type (pellet or meal) were the experimental units for all data analysis. Thus, there were 2 observations per feeder type in the 3 trials that had both meal and pellet diet form. Pen replicates per observation ranged from 6 to 24. Backfat, loin depth, and lean percentage in each study were adjusted to using HCW as a covariate. Results were considered significant at $P \leq 0.05$.

From the meta-analysis results, the growth performances and carcass characteristics were used to calculate an income over feed cost (IOFC) of feeding with WD and CD feeders. Income over feed cost is a method to measure an economic value by assuming that other costs, such as utility and labor, are equal. Feed cost was valued at $278/ton, carcass price at $0.88/lb, and $1.50 for 1% of reduction in lean percentage. The advantage or disadvantage of feeding with a WD vs. a CD feeder was evaluated by the difference in IOFC.

Results and Discussion

The meta-analysis indicated that pigs fed with WD feeders had greater ($P < 0.01$; Table 1) ADG and ADFI compared with those fed with CD feeders, but no difference ($P = 0.93$) was observed in F/G. As a result of improved growth rate, final BW and HCW of pigs fed with WD feeders were 3.2% greater ($P < 0.01$) than when pigs were fed with a CD feeder. For carcass traits, backfat was greater ($P < 0.01$) and percentage lean was lower ($P < 0.01$) in pigs fed with WD feeders compared with those fed with CD feeders. Carcass yield and loin depth did not differ ($P > 0.14$) among feeder types. Water usage for pigs fed with WD feeders was 0.4 gal/pig/d less ($P = 0.02$) than for pigs using CD feeders.

Economic analysis using the result of this meta-analysis shows that WD feeders would provide an advantage of $0.74/pig. If the reduction in lean percentage were not discounted by the processor, the economic advantage would increase to $1.60 per pig. Notably, some experiments have found a negative impact on F/G (0.03 to 4.60%) for pigs fed from WD feeders. This response is a concern, because it was highly variable among the studies and any negative change in F/G would eliminate any economic advantage. Feeder adjustment and stocking rate have been reported to be important variables in influencing F/G of pigs fed with WD feeders. The difference in water usage was not included in this economic analysis; however, the smaller volume of water usage with WD feeder may provide an economic benefit by reducing waste water.

This meta-analysis accounted for both types of feed (meal and pellet), but because of the limited data on pelleted feed (3 experiments), no interaction was observed between diet type and feeder design. Some data[5] suggest a possible interaction between diet type (meal vs. pellet) and feeder design. Researchers have speculated that with CD feeders, pigs fed a pelleted diet have improved F/G compared with those fed a meal diet, but no differences in F/G between diet types when fed with WD feeders. Providing both wet feed and pelleting decreases eating time, but it is speculated that the interaction occurs because these two factors are not additive.

Meta-analysis is a great method to provide quantification of biological difference among different feeder types and allow economic analysis in different circumstances. Pigs fed with WD feeders consistently had increased growth rate, feed intake, final BW, and HCW, but deposited more fat as indicated by greater backfat and lower percentage of lean. The economic return of using WD feeders depends on the feed efficiency response with an economic advantage when feed efficiency is similar among feeder types. However, the F/G response was highly variable; hence, if feed efficiency were poorer due to stocking density or feeder adjustment, any economic value to using WD feeders would be lost.

Table 1. Meta-analysis of growth performance, carcass traits, and water usage in pigs fed with conventional dry (CD) or wet-dry (WD) feeders[1]

Item	No. of observations[2]	Dry	Wet-dry	SEM	Probability, *P*<
ADG, lb	19	1.91	2.00	0.046	0.01
ADFI, lb	19	5.09	5.35	0.222	0.01
F/G	19	2.65	2.65	0.101	0.91
Carcass wt, lb	10	201.6	208.0	2.04	0.01
Backfat, in.[3]	10	0.67	0.71	0.009	0.01
Loin depth, in.	10	2.45	2.42	0.027	0.14
Lean, %	12	51.4	50.8	0.85	0.01
Carcass yield, %	10	75.8	75.6	0.26	0.57
Water disappearance, gal/pig/d	6	1.7	1.3	0.09	0.02
Initial wt, lb	19	74.2	74.1	5.90	0.27
Final wt, lb	19	228.4	235.7	13.80	0.01

[1] Growth performance was evaluated from 15 trials, carcass characteristics (carcass weight, backfat, loin depth, percentage carcass yield) from 8 trials, lean percentage from 9 trials, water disappearance from 5 trials, and response due to diet type (meal vs. pellet) were analyzed from 3 trials.
[2] Numbers of means for feeder type (CD and WD) within experiment and diet types (pellet or meal) that were used in the meta-analysis.
[3] Backfat, loin depth, and lean percentage in each study were adjusted using HCW as a covariate.

[5] Rantanen et al., Swine Day 1995, Report of Progress, pp. 199–120.

Effect of Sampling Method on the Accuracy and Precision of Estimating the Mean Pig Weight of the Population[1,2]

C. B. Paulk, G. L. Highland[3], M. D. Tokach, J. L. Nelssen, S. S. Dritz[4], R. D. Goodband, J. M. DeRouchey, and K. D. Haydon[5]

Summary

Producers have adopted marketing strategies such as topping to help reduce economic losses from weight discounts at the processing plant. Despite adopting these strategies, producers are still missing target weights and incurring discounts. One contributing factor is the error of sampling methods that producers use to estimate the mean weight of the population to determine the optimal time to top pigs. The standard sample size that has been adopted by many producers is 30 pigs. Our objective was to determine the best method for selecting 30 pigs to improve the accuracy and precision of estimating the mean pig weight of the population. Using a computer program developed in R (R Foundation for Statistical Computing, Vienna, Austria), we were able to generate 10,000 sample means for different sampling procedures on 3 different datasets. Using this program we evaluated taking: (1) a completely random sample of 30 pigs from the barn, (2) a varying number of pigs per pen to achieve a total sample size of 30 pigs, (3) selecting the heaviest and lightest pig (determined visually) from 15 pens and calculating the mean from those pigs, and (4) calculating the median of the selected pigs.

Among the 3 datasets, taking a completely random sample of 30 pigs from the barn resulted in a range between the upper and lower confidence interval as high as 23 lb. Increasing the number of pens sampled while keeping the sample size constant reduced the range between the upper and lower confidence interval; however, the confidence interval (range where 95% of weight estimates would fall) was still as high as 24 lb (241 to 265 lb) when only 30 pigs were sampled. Although the range was reduced, it was not enough to make increasing the number of pens sampled a practical means of estimating mean pig weight of the barn. Selecting the heaviest and lightest pigs in 15 pens and taking the mean of the sample resulted in a reduction of the range between the upper and lower confidence interval from 31 to 53%. Although the precision of the sample was improved, accuracy of the sampling method decreased, with the mean of the 10,000 simulations up to 8 lb lighter than the mean of the population.

Selecting the heaviest and lightest pigs can be a valuable method for improving the precision in estimating the mean of the population, but adjustments to the sampling procedure need to be developed to improve its accuracy.

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[1] The authors wish to thank Elanco Animal Health, Greenfield, IN, for providing technical and financial support.

[2] The authors wish to thank Dr. Jason Kelly and Suidae Animal Health and Production, Algona, IA, for providing technical support and access to commercial swine facilities.

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Key words: finishing pig, mean weight estimation, sample size

Introduction

Swine producers must meet processing plant requirements for specific weights of pigs as well as weight ranges to avoid economic penalties. In attempts to reduce these economic penalties, producers have adopted marketing practices such as topping or marketing the heaviest pigs several weeks before the expected barn closeout. Because pig BW typically approximates a normal distribution, subsampling methods to predict the average weight of pigs in the barn can be used to model distributions of BW within the barn. The standard sample size that has been adopted by many producers is 30 pigs. Previous data from Kansas State University reported that for a set sample size, increasing the number of pens sampled could reduce the error in estimating the mean pig weight of the population (Paulk et al., 2011[6]). To maximize economic return when marketing pigs, the precision of sampling pigs needs further improvement; therefore, our objective was to determine the best method of selecting 30 pigs to improve the accuracy and precision of estimating the mean pig weight of the population.

Procedures

A total of 3 datasets (A, B, and C) were used to evaluate sampling method on the accuracy and precision of estimating the pig mean weight in the barn. The first sampling method tested was a completely random sample of 30 pigs from the barn, disregarding pen arrangements. The second sampling method tested compared the number of pigs (1 to 30 pigs) sampled from an increasing number of pens to achieve a total sample size of 30 pigs. The third and fourth sampling methods tested consisted of selecting the heaviest and lightest pig (determined visually) from 15 pens (30 pigs total) and calculating the mean and median of the selected pigs, respectively.

Dataset A was derived from Groesbeck et al. (2007[7]). Dataset A (Figure 1) comprised a total of 1,260 pigs in 48 pens with 23 to 28 pigs per pen. The mean, median, standard deviation and CV of the population were 253.0 lb, 254 lb, 32.8 lb, and 13.0%, respectively. Datasets B and C were obtained for the purposes of this experiment. Dataset B was obtained from a commercial finishing site in northern Iowa. Pigs (PIC C42 × PIC 359) weighed for Dataset B were from a single barn that was classified as healthy by the attending veterinarian. The barn was filled with pigs over a 1-wk period, and pigs were gate cut as they came off the truck to randomly place them in pens. Dataset B (Figure 2) contained a total of 1,261 pigs weighed (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) and housed in 19 pens with 56 to 81 pigs per pen. Dataset C was derived from a different commercial site in northern Iowa that consisted of pigs (Genetiporc F25 × G performer boar) that were weaned during a porcine reproductive and respiratory syndrome (PRRS) outbreak at the sow farm. The barn was filled with pigs over a 1-wk period, and pigs were gate cut as they came off the truck. Dataset C (Figure 3) comprised a total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen.

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[6] Paulk et al., Swine Day 2011. Report of Progress 1056, pp. 308–318.

[7] Groesbeck, G. N., G. Armbuster, M. D. Tokach, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2007. Influence of Pulmotil, Tylan, and Paylean on pig growth performance and weight variation. American Association of Swine Veterinarians Proceedings, pp. 235–238.

A program was coded using R (R Foundation for Statistical Computing, Vienna, Austria) to demonstrate the error associated with varying sampling methods when estimating the mean weight of the population. For the first sampling method, the program was designed to take a completely random sample of the designated sample size, disregarding pen arrangements, and calculate the mean of this sample. The program conducted this sampling technique 10,000 times, generating 10,000 sample means. The 10,000 sample means were sorted from least to greatest, and a 95% confidence interval (CI) was generated by selecting the 9,751st observation (upper CI) and the 250th observation (lower CI). The distances between the upper and lower CI represent the range of the mean estimations. A similar analysis was conducted using R for the remaining sampling methods. For sampling methods 3 and 4, marketers provided by Suidae Health and Production, Algona, IA, were used to select the heaviest and lightest pigs in each pen. One marketer, marketer 1, was provided for Dataset B and two marketers, marketers 2 and 3, were provided for Dataset C. The percentages of accurately selected pigs for each dataset are presented in Table 1. Selection accuracy was incorporated into sampling methods 3 and 4 for Dataset A based on the selection accuracy of the 2 marketers from Dataset C. The probability for selecting the 1st, 2nd, 3rd, 4th, or 5th heaviest pig was 50, 25, 15, 5, and 5%, respectively, and the probability for selecting the 1st, 2nd, 3rd, 4th, or 5th lightest pig was 70, 15, 5, 5, and 5%, respectively. These were chosen because dataset A and C had similar pen arrangements. To account for selection accuracy in the simulations, a rank was assigned to the heaviest and lightest pig selected by the marketer in each pen. Next, these were combined into a list for both groups of selected pigs, the heaviest and lightest pigs. For each pen selected, a rank was randomly selected; therefore, for Dataset A, if the 1st pen randomly selected were pen 8, one pig selected from pen 8 would have a 50, 25, 15, 5, and 5% chance of being either the 1st, 2nd, 3rd, 4th, or 5th heaviest pig, and the other pig selected would have a 70, 15, 5, 5, and 5% chance of being either the 1st, 2nd, 3rd, 4th, or 5th lightest pig, respectively.

Results and Discussion

Notably, random samples were generated using a computer program and samples taken from the barn are not truly random unless pigs are individually identified and preselected, rather than selected by the marketer.

When asked to identify the heaviest pig in the pen, marketers 1, 2, and 3 identified the heaviest pig in 47.4, 43.5, and 55.0% of the pens and the 2nd heaviest pig in 5.3, 35.0, and 25.0% of the pens, respectively (Figures 2, 3, and 4; Table 1). The pigs identified by marketers 1, 2, and 3 were within the actual 5 heaviest pigs in 68, 100, and 95% of the pens, respectively. When asked to select the lightest pig, marketers 1, 2, and 3 identified the lightest pig in 57.9, 75.0, and 68.4% of the pens and the 2nd lightest pig in 21.1, 17.5, and 10.5% of the pens, respectively (Figures 2, 3, and 4; Table 1). The pigs identified by marketers 1, 2, and 3 were within the actual 5 heaviest pigs in 79.5, 100, and 100% of the pens, respectively.

When taking a completely random sample of 30 pigs from datasets A, B, and C, the range between the upper and lower CI was 23.0, 15.0, and 22.5 lb, respectively. For Datasets A and C, when sampling 15 pigs from 2 pens, the estimated range between the upper and lower CI was 32.0 and 47.8 lb, respectively, but when sampling 1 pig from 30 pens the ranges between the upper and lower CI were 23.1 and 20.3 lb, respectively (Table 2). For Dataset B, when sampling 30 pigs from 1 pen, the estimated range between the upper and lower CI was 38.3 lb, but when sampling 2 pigs from 15 pens, the range between the upper and lower CI was 14.8 lb; therefore, increasing the number of pens used to sample 30 pigs can improve the range between the upper and lower CI by 28, 61, and 58% in Datasets A, B, and C, respectively.

Selecting the heaviest and lightest pigs in 15 pens and taking the mean of the sample resulted in a reduction of the range between the upper and lower CI from 31 to 53%, but because specific pigs were selected, bias was introduced into the sampling procedure. This bias resulted in increased systematic error or reduced accuracy, with the mean of the 10,000 simulations being less than the actual mean of the perspective population. When pigs were selected based on the estimated selection (Dataset A), marketer 1 (Dataset B), marketer 2 (Dataset C), and marketer 3 (Dataset C), the means of the 10,000 simulations were 245.0, 207.7, 219.8, 221.8, respectively, whereas the actual means of Datasets A, B, and C were 253.0, 213.5, 222.4 lb, respectively. The deviation in accuracy of the mean can be influenced by the shape of the population distribution and the accuracy of the marketer when selecting both the heaviest and lightest pigs. Taking the median of the selected pigs did not further improve the range between the upper and lower 95% CI.

Sample size, method, variation, and distribution of pigs within a barn can substantially affect the precision of estimating the mean weight of all pigs in the barn. It is important for producers to take this into consideration when weighing pigs prior to topping to make marketing decisions. Calculating the mean of the selected heaviest and lightest pigs in each pen can improve the precision of estimating the mean; however, adjustments to the sampling method need to be determined to improve its accuracy.

Table 1. The percentage of the selected pigs as the actual n heaviest or lightest pig[1]

	Rank of pigs					
	1	2	3	4	5	>5
Heaviest[2]						
Dataset B marketer 1, %	47.4	5.3	0.0	5.3	10.5	31.5
Dataset C marketer 2, %	42.5	35.0	10.0	7.5	5.0	0.0
Dataset C marketer 3, %	55.0	25.0	10.0	2.5	2.5	5.0
Lightest[3]						
Dataset B marketer 1, %	57.9	21.1	10.5	0.0	0.0	10.5
Dataset C marketer 2, %	75.0	17.5	5.0	2.5	0.0	0.0
Dataset C marketer 3, %	68.4	10.5	7.9	5.3	7.9	0.0

[1] Marketers were asked to select the heaviest and lightest pig in each pen in the barn.
[2] 1 is the heaviest pig; 5 is the 5th heaviest pig.
[3] 1 is the lightest pig; 5 is the 5th lightest pig.

Table 2. The resulting mean, upper 95% confidence interval (CI), lower 95% CI, and range for the various sampling methods to give a total sample size of 30 pigs

Sampling method	Mean of 10,000 simulations	Upper CI	Lower CI	Range
Dataset A[1]				
Method 1, 30 random pigs[2]	253.0	264.2	241.2	23.0
Method 2[3]				
15 pigs from 2 pens	253.2	268.6	236.6	32.0
10 pigs from 3 pens	253.1	267.1	238.4	28.8
6 pigs from 5 pens	253.1	266.0	239.4	26.6
5 pigs from 6 pens	253.0	265.6	239.7	26.0
3 pigs from 10 pens	253.1	265.2	240.7	24.6
2 pigs from 15 pens	253.1	264.7	241.2	23.5
1 pig from 30 pens	253.0	264.3	241.2	23.1
Method 3, mean[4]	245.0	252.4	237.7	14.7
Method 4, median[5]	251.6	263.5	240.0	23.5
Dataset B[6]				
Method 1, 30 random pigs[2]	213.4	220.8	205.8	15.0
Method 2[3]				
15 pigs from 2 pens	213.5	224.7	186.4	38.3
10 pigs from 3 pens	213.5	223.9	197.6	26.3
6 pigs from 5 pens	213.6	223.3	201.3	22
5 pigs from 6 pens	213.6	222.5	203.9	18.6
3 pigs from 10 pens	213.5	222	204.6	17.4
2 pigs from 15 pens	213.6	221.3	205.6	15.7
1 pig from 30 pens	213.5	220.9	206.1	14.8
Method 3, mean[4]	207.7	211.3	204.4	6.9
Method 4, median[5]	207.9	218.0	194.5	23.5

continued

Table 2. The resulting mean, upper 95% confidence interval (CI), lower 95% CI, and range for the various sampling methods to give a total sample size of 30 pigs

Sampling method	Mean of 10,000 simulations	Upper CI	Lower CI	Range
Dataset C[7]				
Method 1, 30 random pigs[2]	222.3	233.3	210.8	22.5
Method 2[3]				
15 pigs from 2 pens	223.0	244.6	196.8	47.8
10 pigs from 3 pens	223.1	242.0	201.5	40.4
6 pigs from 5 pens	223.0	238.6	205.9	32.7
5 pigs from 6 pens	223.0	237.5	207.6	30.0
3 pigs from 10 pens	223.0	235.5	209.8	25.7
2 pigs from 15 pens	223.0	234.3	211.3	22.9
1 pig from 30 pens	223.0	233.1	212.8	20.3
Method 3, mean[4]				
Marketer 2	219.8	227.4	212.0	15.5
Marketer 3	221.8	229.6	213.8	15.8
Method 4, median[5]				
Marketer 2	221.0	231.0	210.5	20.5
Marketer 3	222.4	234.5	208.0	26.5

[1]A total of 1,260 pigs were used (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.
[2] 30 pigs were randomly selected from the barn.
[3] The number of random pigs selected from the number of randomly selected pens.
[4] Selecting the heaviest and lightest pig (determined visually) from 15 pens and calculating the mean from those two pigs. The 15 pen means were averaged to obtain an estimated weight of the barn.
[5] Selecting the heaviest and lightest pig (determined visually) from 15 pens and calculating the median from those pigs
[6]A total of 1,261 pigs were used (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) with 56 to 81 pigs per pen and a total of 19 pens.
[7]A total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation= 32.0 lb, and CV = 14.4%) with 20 to 35 pigs per pen and a total of 40 pens.

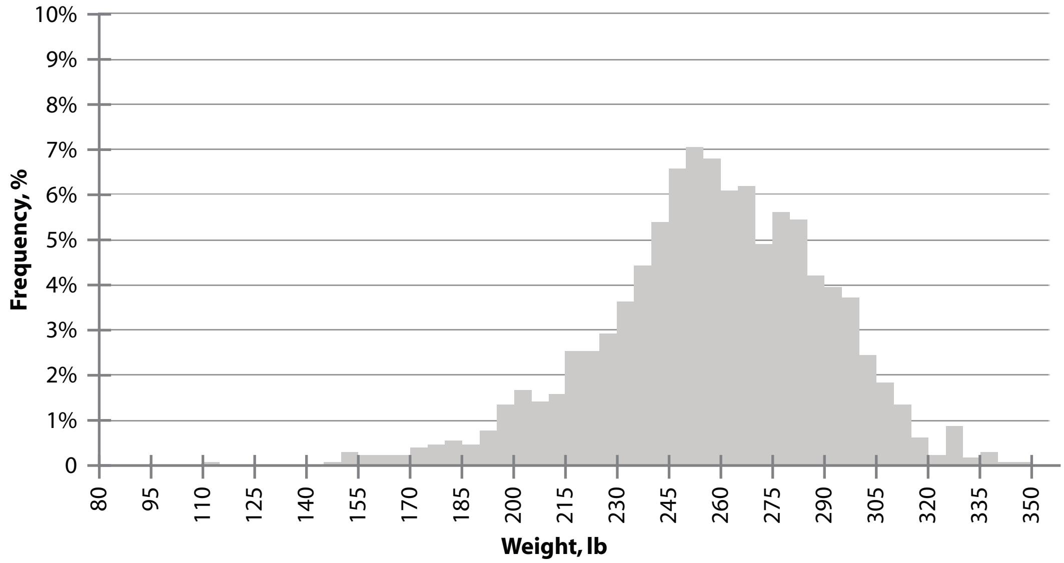

Figure 1. Histogram of Dataset A, a total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 13.0%) with 23 to 28 pigs per pen and a total of 48 pens.

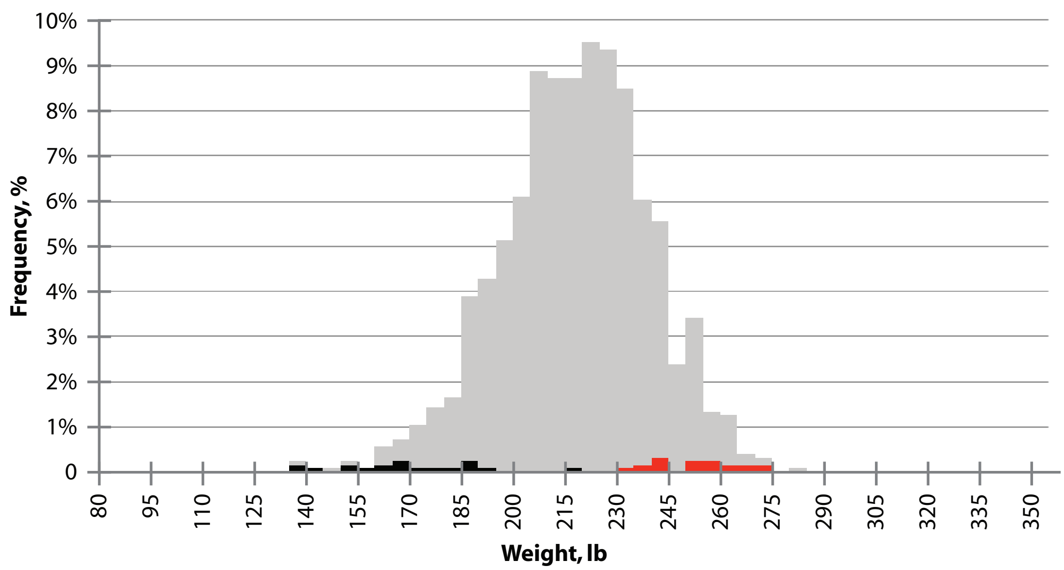

Figure 2. Histogram of Dataset B and marketer 1's selections. A total of 1,261 pigs were weighed (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) with 19 pens and 56 to 81 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The 2 histograms of the marketer's selections are imposed on top of the population histogram.

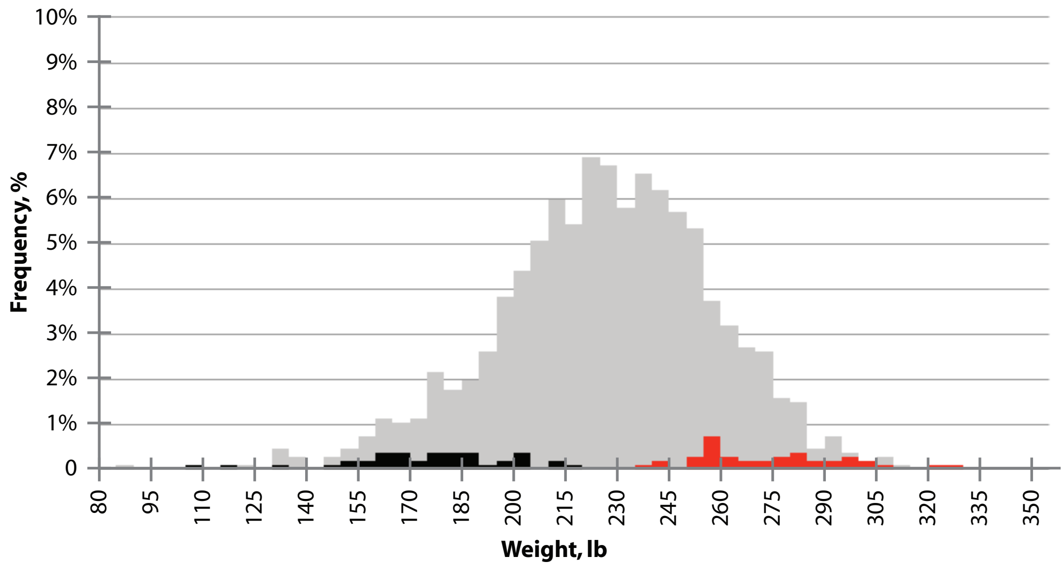

Figure 3. Histogram of Dataset C and marketer 2's selections. A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) with 40 pens and 20 to 35 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The 2 histograms of the marketer's selections are imposed on top of the population histogram.

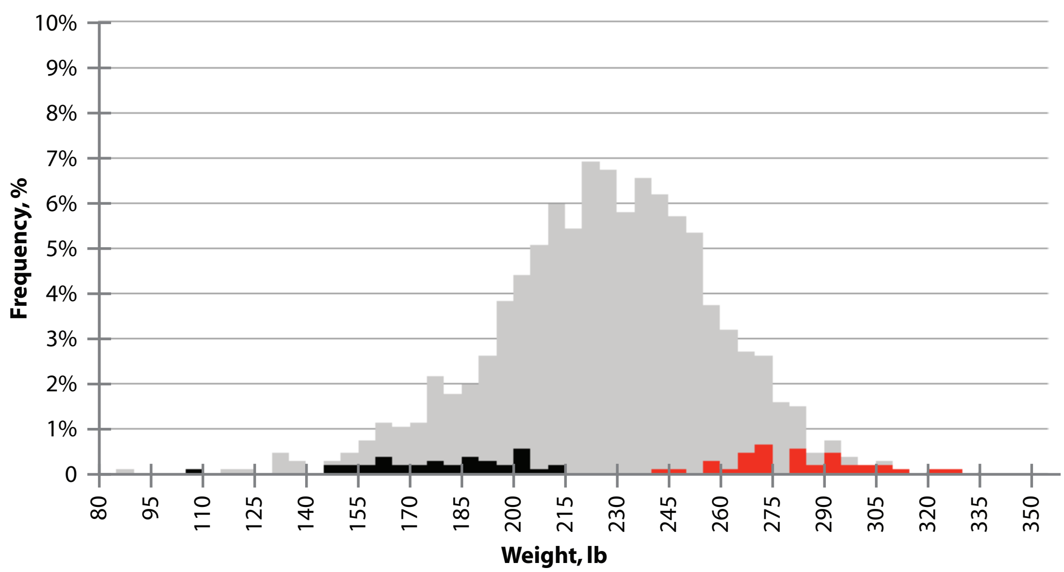

Figure 4. Histogram of Dataset C and marketer 3's selections. A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) with 40 pens and 20 to 35 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The 2 histograms of the marketer's selections are imposed on top of the population histogram.

Effect of Sample Size and Method of Sampling Pig Weights on the Accuracy and Precision of Estimating the Distribution of Pig Weights in a Population[1,2]

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Summary

Producers have adopted marketing strategies such as topping to help reduce economic losses from weight discounts, but they are still missing target weights and incurring discounts. We have previously determined the accuracy of sampling methods producers use to estimate the mean weight of the population. Although knowing the mean weight is important, understanding how much variation or dispersion exists in individual pig weights within a group can also enhance a producer's ability to determine the optimal time to top pigs. In statistics and probability theory, the amount of variation in a population is represented by the standard deviation; therefore, our objective is to determine the sample size and method that is optimal for estimating the standard deviation of BW for a group of pigs in a barn.

Using a computer program developed in R (R Foundation for Statistical Computing, Vienna, Austria), we were able to generate 10,000 sample standard deviations for different sampling procedures on 3 different datasets. Using this program, we evaluated weighing: (1) a completely random sample of 10 to 200 pigs from the barn, (2) an increasing number of pigs per pen from 1 to 15 pigs and increasing the number of pens until all pens in the barn had been sampled, and (3) selecting the heaviest and lightest pig (determined visually) in each pen and subtracting the lightest weight from the heaviest weight and dividing by 6. For all 3 datasets, increasing the sample size of a completely random sample from 10 to 200 pigs decreased the range between the upper and lower confidence intervals (CI) when estimating the standard deviation; however, this occurred at a diminishing rate. For the barn with the most variation, increasing the number of pens sampled while keeping constant the total number of pigs sampled led to a reduction in range between the upper and lower CI by 7, 6, and 31% for Datasets A, B, and C, respectively. Sampling method 3 resulted in a reduction of the range between the upper and lower CI from 9 to 62% for the 3 datasets. These data indicated that the distribution of pig weights can be practically estimated by weighing the heaviest and lightest pigs in 15 pens.

[1] The authors wish to thank Elanco Animal Health (Greenfield, IN) for providing datasets used in analyses and for partial financial support.

[2] The authors wish to thank Dr. Jason Kelly and Suidae Animal Health and Production (Algona, IA) for providing technical support and access to commercial swine facilities.

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Key words: finishing pig, standard deviation estimation, sample size

Introduction

Despite adopting marketing strategies such as topping to help reduce economic losses at the processing plant, swine producers are often missing target weights and incurring substantial weight discounts. We have previously determined the accuracy of sampling methods producers use to estimate the mean weight of the population. Although knowing the mean weight is important, understanding how much variation or dispersion exists in individual pig weights from the mean weight can also enhance a producer's ability to maximize economic return when marketing pigs. Knowing the distribution allows producers to better estimate the ideal timing for removing pigs from a barn. In statistics and probability theory, the amount of variation in a population is represented by the standard deviation; therefore, our objective was to determine the optimal sample size and method for estimating the standard deviation of weights for the population of pigs in the barn.

Procedures

A total of 3 datasets (A, B, and C) in which all pigs in the barn had been weighed individually were used to evaluate sample size and method of sampling on the precision of estimating the variation in pig weights in the barn. The first method of sampling tested was a completely random sample of the barn that disregarded pen arrangements. Samples of different sizes were taken (10, 20, 30 pigs, etc.). The second sampling method tested increasing the number of pigs sampled per pen from 1 to 15 pigs, then increasing the number of pens until all pens had been sampled. The third sampling method consisted of selecting the heaviest and lightest pig (determined visually) from 15 pens (30 pigs total) and dividing the difference in weight between the lightest and heaviest pigs in the total sample by 6.

Dataset A was derived from Groesbeck et al. (2007[6]). Dataset A (Figure 1) contained a total of 1,260 pigs from 48 pens with 23 to 28 pigs per pen. The mean, median, standard deviation and CV of the population were 253.0 lb, 254 lb, 32.8 lb, and 13.0%, respectively. Datasets B and C were obtained for the purposes of this experiment. Dataset B was obtained from a commercial site in northern Iowa. The finishing facility utilized PIC C42 × PIC 359 pigs that were classified as healthy by the farm veterinarian. The barn was filled with pigs over a 1-wk period, and pigs were gate cut as they came off the truck to randomly place them in pens. For dataset B (Figure 2), a total of 1,261 pigs were weighed (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) from 19 pens with 56 to 81 pigs per pen. The 20th pen was used as a recovery pen and was not used for analysis. Dataset C was derived from a different commercial site in northern Iowa that consisted of pigs (Genetiporc F25 × G performer boar) weaned during a porcine reproductive and respiratory syndrome (PRRS) outbreak at the sow farm. The barn was filled with pigs over a 1-wk period, and pigs were gate cut as they came off the truck into pens. For Dataset C (Figure 3), a total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard

[6] Groesbeck, G. N., G. Armbuster, M. D. Tokach, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2007. Influence of Pulmotil, Tylan, and Paylean on pig growth performance and weight variation. American Association of Swine Veterinarians Proceedings, pp. 235–238.

deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen. The barn did not have a recovery pen for sick pigs; therefore, all pens were used for analysis.

A program was coded using R (R Foundation for Statistical Computing, Vienna, Austria) to demonstrate the error that varying sample sizes and methods of selecting pig weights have on the estimation of the standard deviation of a population. For the first method of sampling, the program was designed to take a completely random sample of the designated sample size, disregarding pen arrangements, and calculate the standard deviation of this sample. The standard deviation was calculated as:

Standard deviation = $\sqrt{\frac{1}{N-1}\sum_{i-1}^{N}(x_i - \bar{x})^2}$, where n is the sample size, $\{x_1, x_2, \ldots x_n\}$ are the observed values of the sample items, and $\bar{x}$ is the mean value of these observations.

The program conducted the sampling technique 10,000 times, generating 10,000 sample standard deviation calculations for each sample size (10, 20, 30 pigs, etc.) by randomly selecting the desired number of pig weights from the population. The 10,000 sample standard deviations for each sample size were sorted from least to greatest. A 95% confidence interval (CI) was generated by selecting the 9,751st observation (upper CI) and the 250th observation (lower CI). The distances between the upper and lower CIs represent the range of the mean estimations. A similar analysis was conducted using R for the second method, but the second sampling method tested the sampling error among a varying number of pigs within varying numbers of pens, with 1 to 15 pigs sampled from 1 to all of the pens.

A similar analysis was conducted using R to determine the error associated with sampling method 3. Personnel trained in selecting pigs (marketers) provided by Suidae Health and Production (Algona, IA) chose the heaviest and lightest pigs in each pen. One marketer, marketer 1, was provided for Dataset B, and two marketers, marketers 2 and 3, were provided for Dataset C. Selection accuracy was incorporated into sampling method 3 for Dataset A based on the selection accuracy of the 2 marketers from Dataset C. The probability for selecting the 1st, 2nd, 3rd, 4th, or 5th heaviest pig was 50, 25, 15, 5, and 5%, respectively, and the probability for selecting the 1st, 2nd, 3rd, 4th, or 5th lightest pig was 70, 15, 5, 5, and 5%, respectively. These were chosen because Datasets A and C had similar pen arrangements. To account for selection accuracy in the simulations, a rank was assigned to the heaviest and lightest pig selected by the marketer in each pen. For each pen selected, a rank was randomly selected; therefore, for Dataset A, if the 1st pen randomly selected was pen 8, one pig selected from pen 8 would have a 50, 25, 15, 5, and 5% chance of being either the 1st, 2nd, 3rd, 4th, or 5th heaviest pig and the other pig selected would have a 70, 15, 5, 5, and 5% chance of being either the 1st, 2nd, 3rd, 4th, or 5th lightest pig, respectively.

Results and Discussion

Notably, the random samples were generated using a computer program, but those samples taken from the barn are not truly random unless pigs are individually identified and preselected, rather than being selected by the marketer.

For all 3 datasets, increasing the sample size of a completely random sample from 10 to 200 pigs decreased the range between the upper and lower CI when estimating the standard deviation (Figures 5, 6, and 7). A majority of the improvement in the precision of the estimation occurred when the sample size increased from 10 to 90 pigs (Table 1). The difference in accuracy of sample size between the different datasets is also important to note. This could result from the difference in the variation of each dataset (Figures 1, 2, and 3); for example, Dataset B had less variation, so fewer pigs needed to be sampled to achieve a similar CI range.

Individual pen means ranged from 253 to 276 lb, 186 to 222 lb, and 180 to 228 lb for Datasets A, B, and C, respectively. Individual pen standard deviations ranged from 19 to 47 lb, 15 to 25 lb, and 16 to 44 lb for Datasets A, B, and C, respectively. As both the number of pigs and pens were increased when sampling, the range or distance between the upper and lower CI decreased (Figures 8, 9, 10 and Tables 2, 3, and 4). Increasing the number of pens sampled while keeping the total number of pigs sampled constant at 30 pigs led to a reduction in range between the upper and lower CI (Table 5). For Datasets A and C, when sampling 15 pigs from 2 pens, the estimated range between the upper and lower CI was 19.9 and 25.2 lb, respectively; however, when sampling 1 pig from 30 pens, the range between the upper and lower CI was 18.5 and 17.5 lb for Datasets A and C, respectively. For Dataset B, when sampling 15 pigs from 2 pens, the estimated range between the upper and lower CI was 12.1 lb, but when sampling 1 pig from 30 pens, the range between the upper and lower CI was 11.4 lb. Therefore, increasing the number of pens used when sampling the barn can improve the range between the upper and lower CI by 7, 6, and 31% for Datasets A, B, and C, respectively, but a major improvement occurred only in Dataset C because Dataset C had a larger difference between individual pen means and standard deviations. Because the distribution of pig weights across pens is not known, taking a random sample from an increasing number of pens is recommended when estimating the distribution of pig weights in the barn.

When asked to identify the heaviest pig in the pen, marketers 1, 2, and 3 identified the heaviest pig in 47.4, 43.5, and 55.0% of the pens and the 2nd heaviest pig in 5.3, 35.0, and 25.0% of the pens, respectively (Figures 2, 3, and 4; Table 6). The pigs identified by marketers 1, 2, and 3 were within the actual 5 heaviest pigs in 68, 100, and 95% of the pens, respectively. When asked to select the lightest pig, marketers 1, 2, and 3 identified the lightest pig in 57.9, 75.0, and 68.4% of the pens and the 2nd lightest pig in 21.1, 17.5, and 10.5% of the pens, respectively (Figures 2, 3, and 4; Table 6). The pigs identified by marketers 1, 2, and 3 were within the actual 5 lightest pigs in 89.5, 100, and 100% of the pens, respectively.

Selecting the heaviest and lightest pigs in 15 pens and dividing the difference between the heaviest and lightest pig of the 30 selected pigs by 6 resulted in a reduction of the range between the upper and lower CI (Table 7). Amongst the various datasets, the range was reduced from 9 to 62% compared with randomly selecting 2 pigs from 15 pens. Sampling method 3 is expected to be a good estimator of the standard deviation, because in a population that approximates a normal distribution, 99.9% of observations are should be within plus or minus 3 standard deviations of the mean, a total of 6 standard deviations between the heaviest and lightest observation; consequently, selecting the heaviest and lightest weight of the distribution and dividing by 6 should approximate the standard deviation of the population.

Sample size, method, variation, and distribution of pigs within a barn can substantially affect the precision of estimating the distribution of pig weights. As expected, sample size to obtain similar CI estimates is reduced if the population is less variable. Finally, these data indicate that the distribution of pig weights can be estimated practically by weighing the heaviest and lightest pigs in 15 pens.

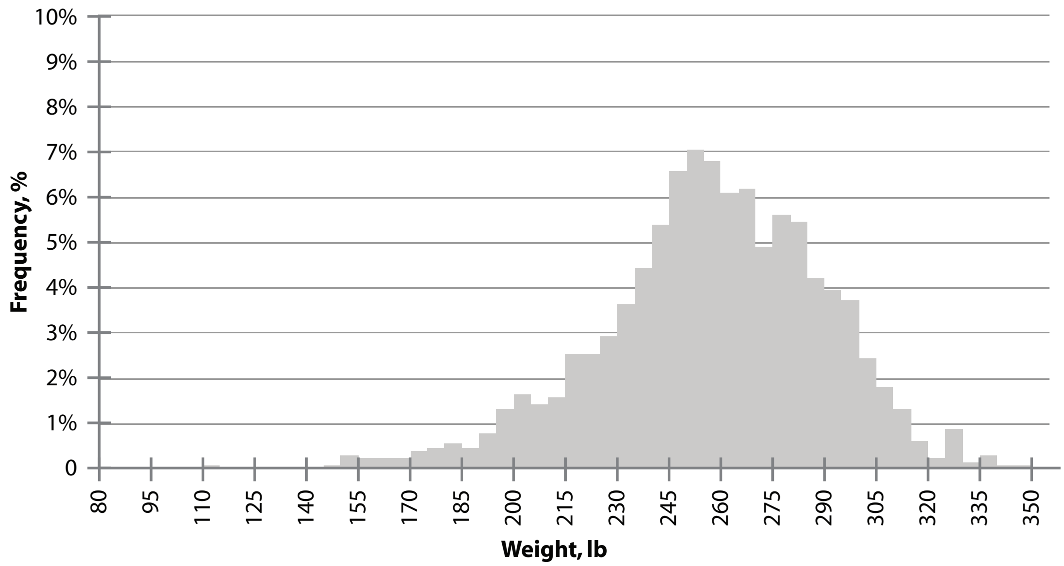

Figure 1. Histogram of Dataset A, a total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.

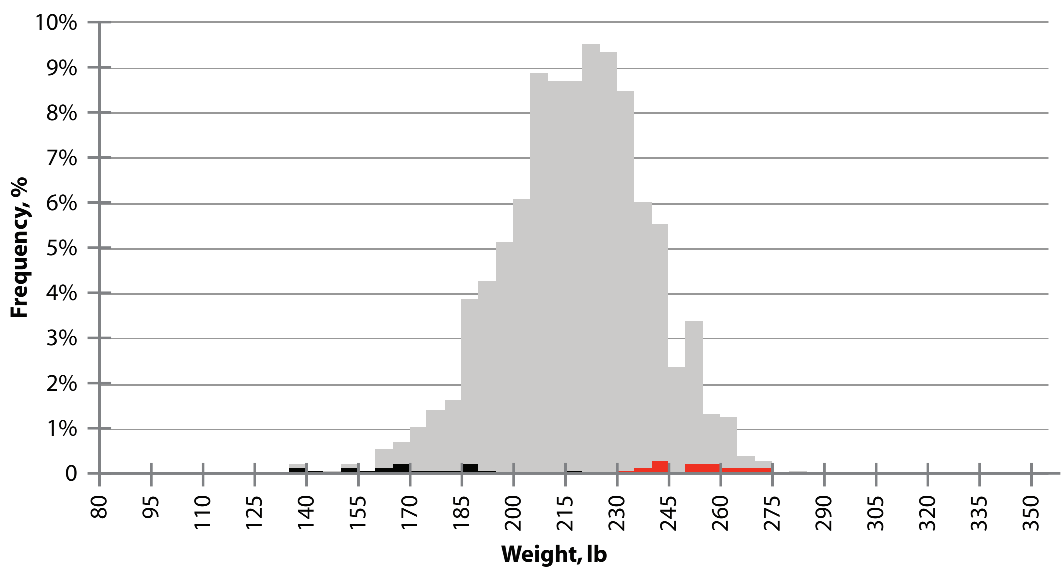

Figure 2. Histogram of Dataset B and marketer 1's selections. A total of 1,261 pigs were weighed (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%), with 19 pens and 56 to 81 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The 2 histograms of the marketer's selections are imposed on top of the population histogram.

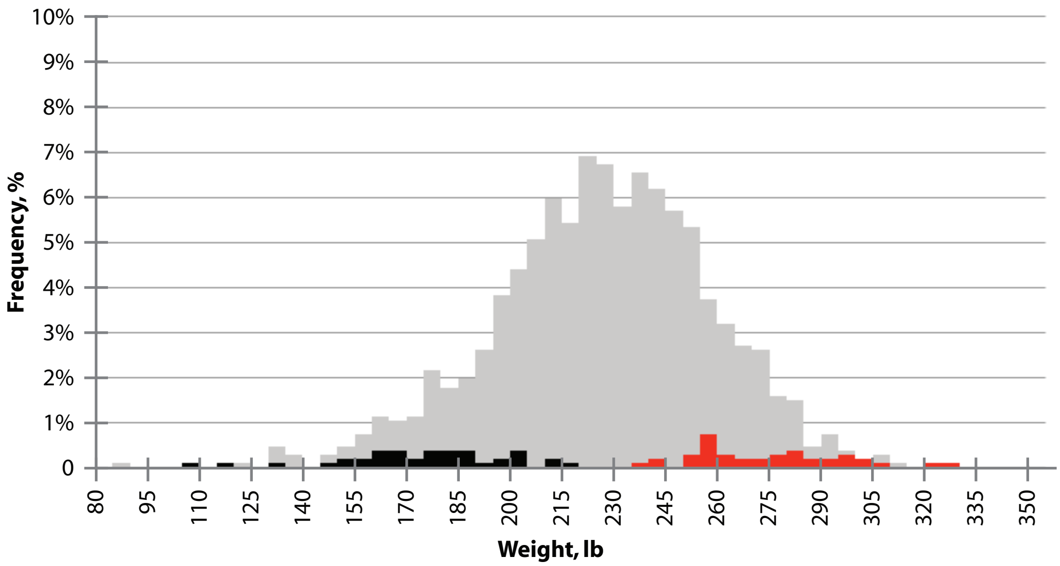

Figure 3. Histogram of Dataset C and marketer 2's selections. A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%), with 40 pens and 20 to 35 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The histograms of the lightest and heaviest of the selections are imposed on top of the population histogram.

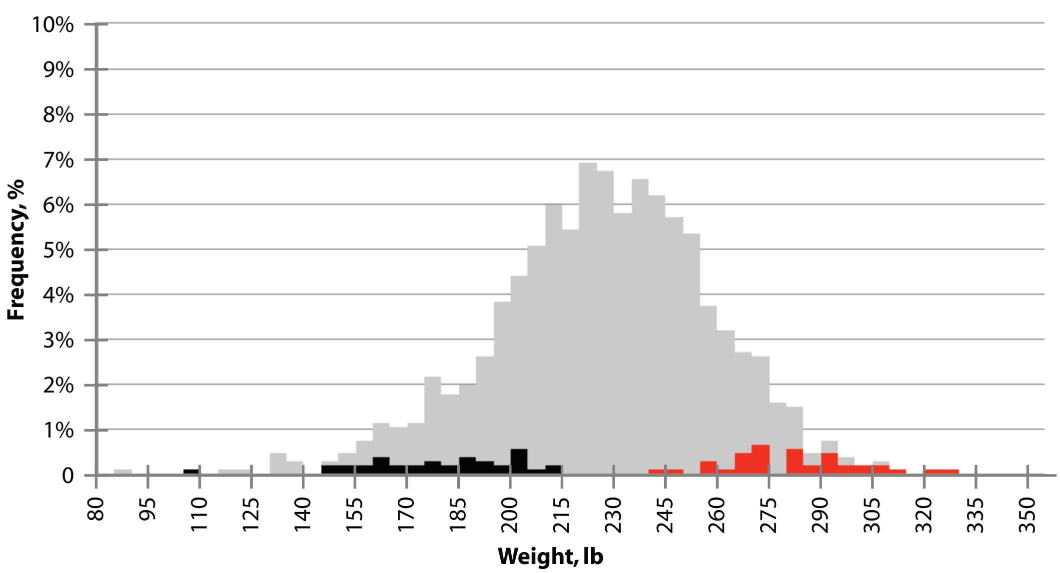

Figure 4. Histogram of Dataset C and marketer 3's selections. A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%), with 40 pens and 20 to 35 pigs per pen. The marketer selected the heaviest and lightest pig in each pen. The histograms of the lightest and heaviest selections are imposed on top of the population histogram.

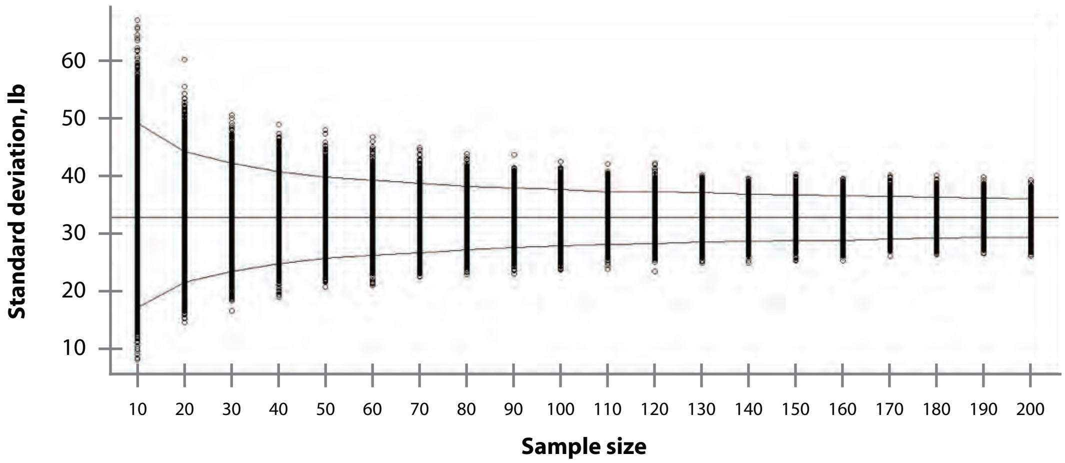

Figure 5. For dataset A, individual pig weights were collected on a total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample sizes (10, 20, 30, etc.) and calculating the standard deviation. This operation was completed 10,000 times for each sample size. Each point represents the standard deviation calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population standard deviation.

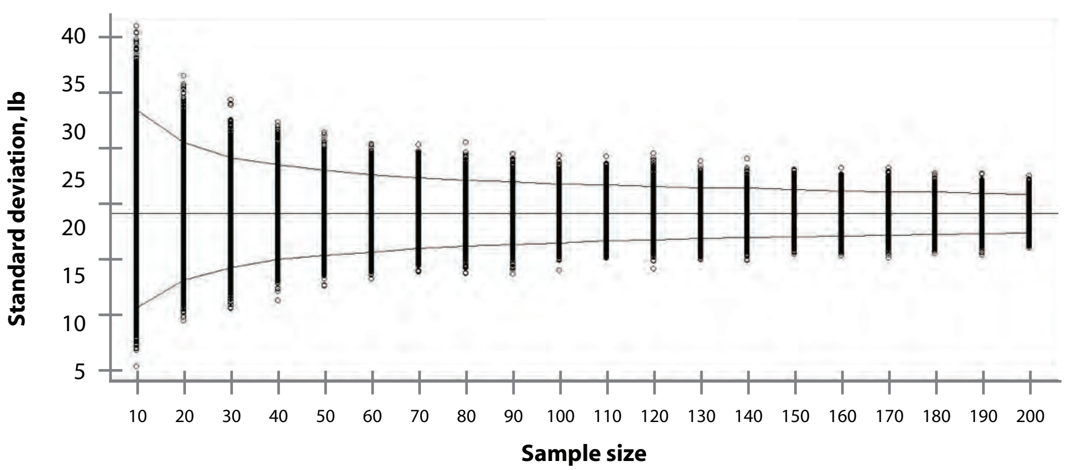

Figure 6. For Dataset B, individual pig weights were collected on a total of 1,261 pigs (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) from 19 pens with 56 to 81 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample size (10, 20, 30, etc.) and calculating the standard deviation. This operation was completed 10,000 times for each sample size. Each point represents the standard deviation calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population standard deviation.

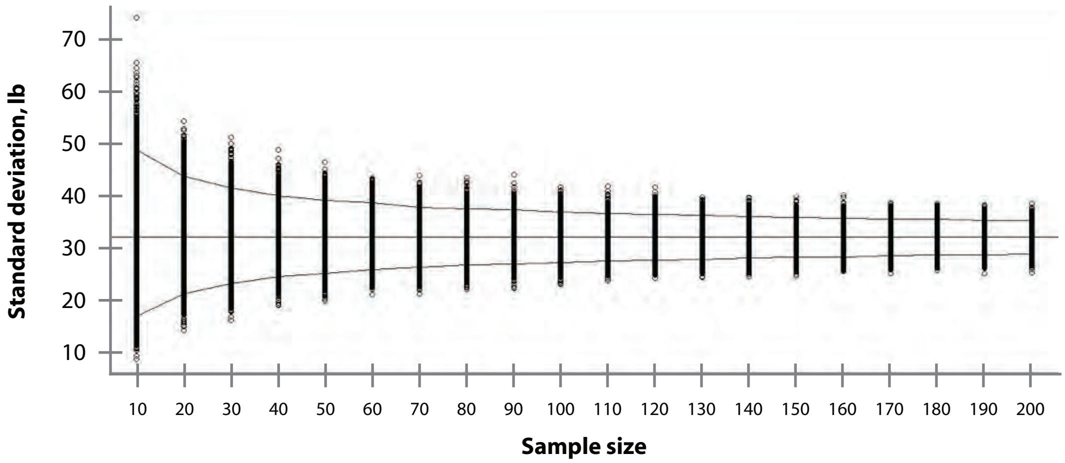

Figure 7. For Dataset C, individual pig weights were collected on a total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample size (10, 20, 30, etc.) and calculating the standard deviation. This operation was completed 10,000 times for each sample size. Each point represents the standard deviation calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population standard deviation.

Table 1. The mean standard deviation, upper confidence interval (CI), lower confidence interval, and range of estimates of the standard deviation when taking a completely random sample of 30, 60, 90, or 120 pigs from the datasets

Sampling method	Mean of 10,000 simulations[1]	Upper CI	Lower CI	Range
Dataset A[2]				
30 pigs	32.5	42.2	23.5	18.7
60 pigs	32.6	39.3	26.4	13.0
90 pigs	32.7	38.0	27.6	10.4
120 pigs	32.8	37.3	28.3	9.0
Dataset B[3]				
30 pigs	21.3	27.3	15.7	11.6
60 pigs	21.4	25.5	17.4	8.2
90 pigs	21.4	24.8	18.2	6.5
120 pigs	21.5	24.3	18.7	5.7
Dataset C[4]				
30 pigs	31.7	41.4	23.2	18.2
60 pigs	31.9	38.6	25.9	12.7
90 pigs	32.0	37.3	26.9	10.4
120 pigs	32.0	36.4	27.7	8.8

[1] The standard deviation was calculated for each of the generated samples, and the mean of the 10,000 generated standard deviation estimates was determined.
[2] A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.
[3] A total of 1,261 pigs (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) with 56 to 81 pigs per pen and atotal of 19 pens.
[4] A total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) with 40 pens and 20 to 35 pigs per pen.

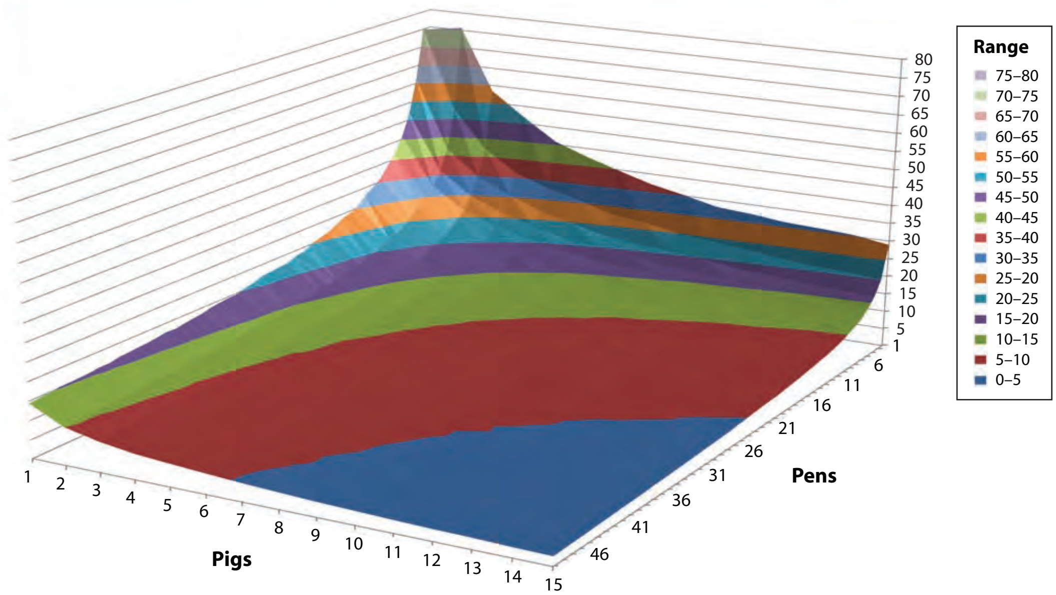

Figure 8. For Dataset A, individual pig weights were collected on a total of 1,260 pigs (actual population weight = 253.0 lb and CV = 12.98%) from 48 pens with 23 to 28 pigs per pen. The dataset was analyzed by estimating the overall standard deviation by altering the number of pigs selected within pens, and total number of pens sampled. This operation was completed 10,000 times for each sampling method, and the range or difference between the upper and lower CI was calculated. Each point on this graph shows the range between the upper and lower CI, represented in pounds.

Table 2. The range between the upper and lower confidence interval (CI) for varying pigs and pen as presented in Figure 7 (Dataset A)[1]

	Number of pigs from each pen														
Pens, n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		76	58	52	46	43	40	37	35	33	32	31	31	30	29
2	75	53	42	36	33	31	28	27	25	24	23	22	21	21	20
3	61	42	35	31	27	25	23	21	21	20	18	18	17	17	16
4	52	36	30	26	23	21	20	19	18	17	16	16	15	14	14
5	46	32	26	23	21	19	17	17	16	15	14	14	13	13	12
6	42	30	25	21	19	18	16	15	14	14	13	12	12	12	11
7	39	28	23	20	18	16	15	14	13	13	12	11	11	10	10
8	36	26	21	18	16	15	14	13	12	12	11	11	10	10	9
9	34	24	20	17	15	14	13	12	12	11	10	10	10	9	9
10	33	23	19	16	15	13	12	11	11	10	10	9	9	9	8
11	31	22	18	16	14	13	12	11	10	10	9	9	8	8	8
12	29	21	17	15	13	12	11	11	10	9	9	8	8	8	8
13	29	20	17	14	13	11	11	10	9	9	8	8	8	7	7
14	27	19	16	14	12	11	10	10	9	9	8	8	7	7	7
15	26	18	15	13	12	11	10	9	9	8	8	8	7	7	7
16	26	18	15	13	11	10	9	9	8	8	7	7	7	7	6

continued

Table 2. The range between the upper and lower confidence interval (CI) for varying pigs and pen as presented in Figure 7 (Dataset A)[1]

	Number of pigs from each pen														
Pens, n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
17	25	18	14	12	11	10	9	9	8	8	7	7	7	6	6
18	24	17	14	12	11	10	9	8	8	7	7	7	6	6	6
19	23	16	13	12	10	9	9	8	8	7	7	6	6	6	6
20	22	16	13	11	10	9	8	8	7	7	6	6	6	6	6
21	22	16	13	11	10	9	8	8	7	7	6	6	6	6	5
22	22	15	12	11	9	9	8	7	7	7	6	6	6	5	5
23	22	15	12	11	9	8	8	7	7	6	6	6	5	5	5
24	21	15	12	10	9	8	8	7	7	6	6	6	5	5	5
25	20	14	12	10	9	8	7	7	6	6	6	5	5	5	5
26	20	14	11	10	9	8	7	7	6	6	6	5	5	5	4
27	20	14	11	10	8	8	7	6	6	6	5	5	5	5	4
28	19	14	11	9	8	7	7	6	6	6	5	5	5	4	4
29	19	13	11	9	8	7	7	6	6	5	5	5	5	4	4
30	18	13	11	9	8	7	6	6	6	5	5	5	4	4	4
31	18	13	10	9	8	7	6	6	5	5	5	5	4	4	4
32	18	13	10	9	8	7	6	6	5	5	5	4	4	4	4
33	17	12	10	9	8	7	6	6	5	5	5	4	4	4	4
34	18	12	10	8	7	7	6	6	5	5	5	4	4	4	4
35	17	12	10	8	7	7	6	5	5	5	4	4	4	4	4
36	17	12	9	8	7	6	6	5	5	5	4	4	4	4	3
37	17	12	9	8	7	6	6	5	5	5	4	4	4	4	3
38	16	12	9	8	7	6	6	5	5	4	4	4	4	3	3
39	16	11	9	8	7	6	6	5	5	4	4	4	4	3	3
40	16	11	9	8	7	6	5	5	5	4	4	4	3	3	3
41	16	11	9	8	7	6	5	5	5	4	4	4	3	3	3
42	16	11	9	7	7	6	5	5	4	4	4	4	3	3	3
43	15	11	9	7	6	6	5	5	4	4	4	3	3	3	3
44	15	11	8	7	6	6	5	5	4	4	4	3	3	3	3
45	15	10	8	7	6	6	5	5	4	4	4	3	3	3	3
46	15	10	8	7	6	5	5	4	4	4	4	3	3	3	3
47	15	10	8	7	6	5	5	4	4	4	3	3	3	3	3
48	14	10	8	7	6	5	5	4	4	4	3	3	3	3	2

[1] Colors match the color scheme in Figure 8, representing a range of 5 lb for each color.

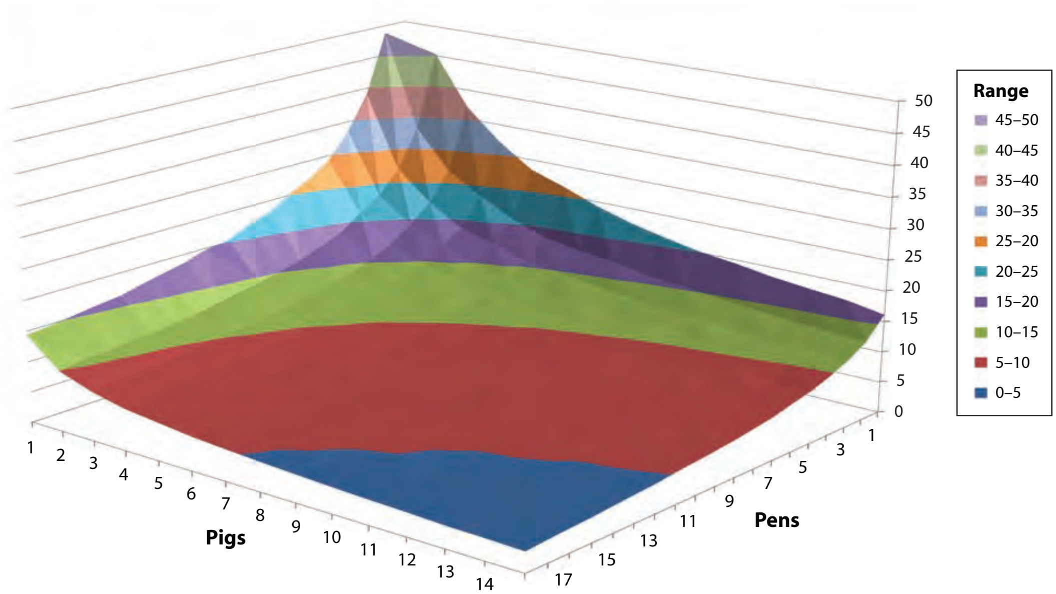

Figure 9. For Dataset B, individual pig weights were collected on a total of 1,261 pigs (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) from 19 pens with 56 to 81 pigs per pen. The dataset was analyzed by altering the number of pigs selected within pens, and total number of pens sampled. This operation was completed 10,000 times for each sampling method, and the range or difference between the upper and lower CI was calculated. Each point on this graph shows the range between the upper and lower CI, represented in pounds.

Table 3. The range between the upper and lower confidence interval (CI) for varying pigs and pen as presented in Figure 7 (Dataset B)[1]

	Number of pigs from each pen														
Pens, n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		45	37	32	28	26	24	23	21	20	19	18	18	17	16
2	49	33	27	24	21	19	18	17	16	15	15	14	14	13	13
3	39	27	22	19	17	16	15	14	13	13	13	12	12	11	11
4	33	23	19	17	15	14	13	12	12	11	11	11	10	10	10
5	29	21	17	15	13	12	12	11	10	10	10	9	9	9	9
6	27	19	15	14	12	11	11	10	9	9	9	8	8	8	8
7	25	17	14	13	11	10	10	9	9	8	8	8	8	7	7
8	23	16	13	12	11	10	9	8	8	8	7	7	7	7	7
9	22	15	12	11	10	9	8	8	8	7	7	7	6	6	6
10	20	14	12	10	9	8	8	8	7	7	6	6	6	6	6
11	20	14	11	10	9	8	8	7	7	6	6	6	6	6	5
12	19	13	11	9	8	8	7	7	6	6	6	5	5	5	5
13	18	12	10	9	8	7	7	6	6	6	6	5	5	5	5
14	17	12	10	8	7	7	6	6	6	5	5	5	5	5	4
15	16	11	9	8	7	7	6	6	5	5	5	5	4	4	4
16	16	11	9	8	7	6	6	5	5	5	5	4	4	4	4
17	15	11	9	7	7	6	6	5	5	5	4	4	4	4	4
18	15	10	8	7	6	6	5	5	5	4	4	4	4	4	4
19	14	10	8	7	6	6	5	5	4	4	4	4	4	3	3

[1] Colors match the color scheme in Figure 9, representing a range of 5 lb for each color.

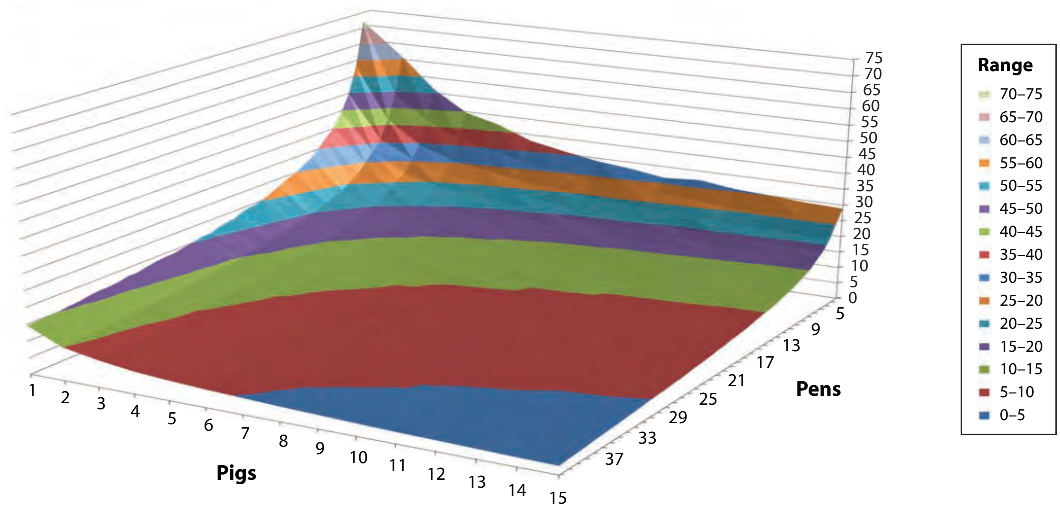

Figure 10. For Dataset C, individual pig weights were collected on a total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen. The dataset was analyzed by altering the number of pigs selected within pens, and total number of pens sampled. This operation was completed 10,000 times for each sampling method, and the range or difference between the upper and lower CI was calculated. Each point on this graph shows the range between the upper and lower CI, represented in pounds.

Table 4. The range between the upper and lower confidence interval (CI) for varying pigs and pen as presented in Figure 10 (dataset C)[1]

	Number of pigs from each pen														
Pens, n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		61	51	45	42	38	36	34	33	31	32	31	30	29	29
2	72	49	42	37	34	32	31	29	29	27	27	26	25	26	25
3	58	42	34	31	29	27	26	25	24	24	23	22	22	21	21
4	50	36	31	27	25	24	23	22	21	21	20	20	19	19	18
5	44	33	27	24	23	21	21	19	19	18	18	17	17	17	17
6	40	30	25	23	21	19	18	18	17	16	16	16	16	15	15
7	38	27	24	21	19	18	17	16	16	15	15	15	14	14	14
8	35	26	21	19	18	17	16	15	15	14	14	14	13	13	13
9	33	24	20	18	17	16	15	14	14	14	13	13	13	12	12
10	31	23	19	17	16	15	14	13	13	13	12	12	12	12	12
11	30	21	18	16	15	14	13	13	12	12	12	11	11	11	11
12	29	21	17	15	14	14	13	12	12	11	11	11	11	10	10
13	27	20	17	15	14	13	12	12	11	11	11	10	10	10	10
14	26	19	16	14	13	12	12	11	11	10	10	10	10	9	9
15	25	18	15	14	12	12	11	11	10	10	10	9	9	9	9
16	24	18	15	13	12	11	11	10	10	10	9	9	9	9	9
17	24	17	14	13	11	11	10	10	9	9	9	9	9	8	8

continued

Table 4. The range between the upper and lower confidence interval (CI) for varying pigs and pen as presented in Figure 10 (dataset C)[1]

	Number of pigs from each pen														
Pens, n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
18	23	16	14	12	11	10	10	9	9	9	8	8	8	8	8
19	22	16	13	12	11	10	10	9	9	8	8	8	8	8	7
20	22	15	13	12	10	10	9	9	8	8	8	8	8	7	7
21	21	15	13	11	10	10	9	8	8	8	8	7	7	7	7
22	21	14	12	11	10	9	9	8	8	8	7	7	7	7	7
23	20	14	12	11	9	9	8	8	8	7	7	7	7	7	6
24	20	14	12	10	9	9	8	8	7	7	7	7	6	6	6
25	19	14	11	10	9	8	8	7	7	7	7	6	6	6	6
26	19	13	11	10	9	8	8	7	7	7	6	6	6	6	6
27	19	13	11	9	9	8	7	7	7	6	6	6	6	6	5
28	18	13	11	9	8	8	7	7	6	6	6	6	5	5	5
29	17	13	10	9	8	7	7	6	6	6	6	5	5	5	5
30	17	12	10	9	8	7	7	6	6	6	5	5	5	5	5
31	17	12	10	8	8	7	6	6	6	5	5	5	5	5	4
32	17	12	10	8	7	7	6	6	6	5	5	5	5	4	4
33	17	11	9	8	7	7	6	6	5	5	5	5	4	4	4
34	16	11	9	8	7	6	6	5	5	5	5	4	4	4	4
35	16	11	9	8	7	6	6	5	5	5	4	4	4	4	4
36	15	11	9	8	7	6	5	5	5	4	4	4	4	4	3
37	15	11	9	7	6	6	5	5	5	4	4	4	4	3	3
38	15	11	8	7	6	6	5	5	4	4	4	4	3	3	3
39	15	10	8	7	6	6	5	5	4	4	4	3	3	3	3
40	15	10	8	7	6	5	5	4	4	4	3	3	3	3	3

[1] Colors match the color scheme in Figure 10, representing a range of 5 lb for each color.

Table 5. The resulting mean, upper confidence interval (CI), lower CI, and range when sampling a varying number of pigs and pens to give a total sample size of 30 pigs when estimating the standard deviation of the population

Sampling method	Mean of 10,000 simulations[1]	Upper CI	Lower CI	Range
Dataset A[2]				
15 pigs from 2 pens	32.0	42.9	23.0	19.9
10 pigs from 3 pens	32.2	42.6	23.0	19.6
6 pigs from 5 pens	32.4	42.5	23.2	19.3
5 pigs from 6 pens	32.4	42.3	23.4	18.9
3 pigs from 10 pens	32.5	42.5	23.6	18.8
2 pigs from 15 pens	32.6	42.5	23.5	19.0
1 pig from 30 pens	32.5	42.3	23.8	18.5
Dataset B[3]				
30 pigs from 1 pen	19.8	26.1	14.0	12.1
15 pigs from 2 pens	20.6	27.5	14.6	12.9
10 pigs from 3 pens	20.9	27.9	15.0	12.9
6 pigs from 5 pens	21.1	27.6	15.3	12.3
5 pigs from 6 pens	21.2	27.6	15.3	12.3
3 pigs from 10 pens	21.3	27.5	15.8	11.7
2 pigs from 15 pens	21.4	27.3	15.9	11.4
Dataset C[4]				
15 pigs from 2 pens	29.0	45.0	19.8	25.2
10 pigs from 3 pens	29.9	43.9	20.3	23.6
6 pigs from 5 pens	30.5	42.6	21.2	21.3
5 pigs from 6 pens	30.7	42.3	21.4	20.9
3 pigs from 10 pens	31.1	41.6	22.4	19.2
2 pigs from 15 pens	31.3	41.2	22.8	18.5
1 pig from 30 pens	31.4	40.6	23.1	17.5

[1] The standard deviation was calculated for each of the generated samples, and the mean of the 10,000 generated standard deviation estimates was determined.

[2] A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) from 48 pens with 23 to 28 pigs per pen.

[3] A total of 1,261 pigs (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) from 19 pens with 56 to 81 pigs per pen.

[4] A total of 1,069 pigs weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen.

Table 6. The percentage of the selected pigs as the actual n heaviest or lightest pig[1]

	Rank of pigs					
	1	2	3	4	5	>5
Heaviest[2]						
Dataset B marketer 1, %	47.4	5.3	0.0	5.3	10.5	31.5
Dataset C marketer 2, %	42.5	35.0	10.0	7.5	5.0	0.0
Dataset C marketer 3, %	55.0	25.0	10.0	2.5	2.5	5.0
Lightest[3]						
Dataset B marketer 1, %	57.9	21.1	10.5	0.0	0.0	10.5
Dataset C marketer 2, %	75.0	17.5	5.0	2.5	0.0	0.0
Dataset C marketer 3, %	68.4	10.5	7.9	5.3	7.9	0.0

[1] Marketers were asked to select the heaviest and lightest pig in each pen in the barn.
[2] 1 is the heaviest pig; 5 is the 5th heaviest pig.
[3] 1 is the lightest pig; 5 is the 5th lightest pig.

Table 7. The resulting mean standard deviation, upper 95% confidence interval (CI), lower 95% CI, and range for the various sampling methods with a total sample size of 30 pigs

Sampling method	Mean standard deviation	Upper CI	Lower CI	Range
Dataset A[1]				
Method 1, 30 random pigs[2]	32.5	42.2	23.5	18.7
Method 2, 2 pigs from 15 pens[3]	32.6	42.5	23.5	19.0
Method 3[4]	32.1	39.2	27.3	11.8
Dataset B[5]				
Method 1, 30 random pigs[2]	21.3	27.3	15.7	11.6
Method 2, 2 pigs from 15 pens[3]	21.4	27.3	15.9	11.4
Method 3[4]	22.8	24.2	19.8	4.3
Dataset C[6]				
Method 1, 30 random pigs[2]	31.7	41.4	23.2	18.2
Method 2, 2 pigs from 15 pens[3]	31.3	41.2	22.8	18.5
Method 3[4]				
Marketer 2	32.2	40.3	23.5	16.8
Marketer 3	32.3	40.3	23.8	16.5

[1] A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) from 48 pens with 23 to 28 pigs per pen.
[2] 30 pigs were randomly selected from the barn.
[3] 2 random pigs were selected from 15 randomly selected pens.
[4] Select the heaviest and lightest pig (determined visually) in each pen, subtract the lightest weight from the heaviest weight, and divide by 6.
[5] A total of 1,261 pigs (population mean = 213.5 lb, median = 214 lb, standard deviation = 21.5 lb, and CV = 10.1%) from 19 pens with 56 to 81 pigs per pen.
[6] A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224 lb, standard deviation = 32.0 lb, and CV = 14.4%) from 40 pens with 20 to 35 pigs per pen.

Comparison of Pig Restraint, Sampling Methods, and Analysis on Blood Lactate Concentration

B.L. Buzzard, L.N. Edwards-Callaway, R. D. Goodband, D.B. Anderson[1], T.E. Engle[1], and T. Grandin[1]

Summary

The objective of the study was to examine the effects of restraint and blood sampling method on blood lactate concentration (LAC) in pigs. Restraint methods used were snaring or restraint with sorting boards. Blood was sampled from 120 pigs at approximately 165 d of age (278.0 ± 6.4 lb) over 2 consecutive days. Each day, 30 pigs were sampled per method. All pigs were housed in one barn, and pigs in adjacent pens were not sampled simultaneously. Snaring consisted of a trained handler snaring each pig while blood was collected via jugular venipuncture (approximately 7 mL). Restraint with sorting boards consisted of a trained handler restraining each pig with two sorting boards and the side of the pen to form a three-sided barrier to reduce pig movement. The distal ear vein was pricked with a 20-gauge needle to obtain several drops of blood for LAC analysis. Lactate concentration was measured using a handheld lactate analyzer. The duration of restraint and a behavior score (1 to 4; 1 = no vocalization or movement and 4 = constant movement, vocalization, and struggle) for each pig were recorded during sampling. Blood lactate was compared between the 2 sampling methods and duration of restraint was used as a covariate in the analysis.

Results indicated that snared pigs had greater ($P = 0.04$) LAC than pigs restrained using the sorting board method, 2.4 ± 0.1 and 2.1 ± 0.1 mM, respectively. Both measurements of LAC were considerably lower than the baseline LAC reported in published literature. A positive correlation (r = 0.42, $P = 0.001$) was observed between duration and LAC for pigs that were restrained by snaring; the longer the restraint duration, the greater the LAC. Positive correlations were observed between duration and behavior score (r = 0.41, $P = 0.001$), duration and LAC (r = 0.64, $P = 0.001$) and behavior score and LAC (r = 0.26, $P = 0.05$) in pigs restrained with sorting boards. In the boarded group, longer durations and higher behavior scores were related to increased LAC. In addition to analyzing behavior, duration of restraint, and LAC, different methods of blood analysis were measured to determine whether the analysis method affected LAC. Samples for this trial were collected from exsanguination blood from a separate set of 56 market-weight pigs to the same specifications as restraint blood samples. Both serum and plasma were analyzed using 3 methods — YSI analyzer, handheld lactate analyzer, and ELISA plate reader — to compare the differences in LAC. Results showed significant variation in values obtained from the three different methods of analysis ($P = 0.001$). Additionally, values obtained from serum differed significantly from values obtained from plasma ($P < 0.001$). When comparing LAC values across studies, attention should be given to the medium of measurement and the method of analysis to make reliable comparisons.

Key words: blood, laboratory, lactate, nursery pig, restraint, stress

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Introduction

Understanding animal well-being is a vital component in the production equation. An animal that is not being cared for properly will not be efficient. Well-being can be affected by stress, for which there are several physiological indicators such as epinephrine, cortisol, and lactate. Blood lactate concentration (LAC) has been used as a determinant of stress in pigs (Benjamin et al., 2001[2]; Hambrecht et al., 2004[3]; Edwards, 2010[4]) because it delivers a quick value and does not require a large blood sample. Through experimentation and measurement of such indicators, animal scientists have been able to determine what practices and situations are stressful to an animal (Hamilton et al. 2004[5]; Hambrecht et al. 2005[6]; Grandin, 2010[7]).

Experimental procedures have drawbacks; for instance, collecting samples from animals is often stressful in itself, thereby affecting the measurement obtained from the sample. Furthermore, opinions vary about what method of sampling is the least stressful to the animal. The objective of this study was to compare two different methods of restraint, snout snaring and sorting boards, while evaluating behavior and measuring LAC.

A wide variety of methods are used to analyze LAC, which can increase the complexity of comparing studies that utilize differing methods of analysis. LAC can be measured in both serum and plasma, but it is not known which medium provides a more accurate measurement. Moreover, researchers do not use the same method of analysis for every experiment, which renders comparisons between research studies difficult. An additional objective of this study was to analyze serum and plasma with three different methods and compare the results to evaluate which method provides a more precise and accurate value of LAC.

Procedures

All animal use, handling, and sampling techniques described herein were approved by the Kansas State University Animal Care and Use Committee.

One hundred-twenty cross-bred pigs (58 barrows and 62 gilts) were used during this study (TR 4 × 1050, PIC, USA, Hendersonville, TN) with an average weight of 278.0 ± 6.4 lb. Pigs were housed and observed in the finishing facility at the K-State Swine Teaching Research Unit. The pigs were kept in two different sizes of pens with slatted

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[7] Grandin, T. 2010. Electric prodding or jamming of pigs during pre-slaughter handling increases stress and raises lactate levels. Abstract.

floors; both sizes of pens allotted 8 ft^2/pig. The larger pen was constructed by removing gates between two smaller pens. Both pens contained one feeder and cup waterer per pen; in the large pens, 16 pigs were allotted 1.75 in. of feeder space, and in the small pens, 8 pigs were allotted 3.5 in. of feeder space. The facility was climate controlled with an average temperature of 59.9°F during the study. Each pig was identified with a unique ear notch. Pigs were provided with ad libitum feed and water; their diet was corn-soy–based with 20% dried distillers grains with solubles (DDGS), fed in meal form, and manufactured at the K-State Animal Science Feed Mill.

Samples for the laboratory method analysis portion of the trial were collected from 56 market weight pigs raised and housed at the K-State Swine Teaching and Research Center. Pigs had previously been part of a trial examining the effects of supplementing Astaxanthin to pigs. Pigs were slaughtered in the K-State Meat Laboratory.

Two different methods of blood sampling and restraint methods were used in this experiment: (1) restraint with sorting boards and blood sampling from a distal ear vein and (2) restraint with a standard snout snare and blood sampling from the jugular vein. Sixty animals per method were used in this trial, which took place over the course of 2 days. During the experiment, no pig was sampled twice, but due to the different sizes of pens, the larger pens were entered twice to obtain samples from different pigs. Restraint with the sorting boards was performed by a trained researcher forming a 3-sided barrier with the boards and the pen to restrict pig movement while another researcher pricked one of the pig's distal ear veins with a retractable 20-gauge needle. A sample strip was inserted into a handheld lactate analyzer (Lactate Scout; EKF Diagnostic GmbH, Magdeburg, Germany), and a drop of blood from the pig's ear was immediately administered to the sample strip. The analyzer provided LAC in approximately 15 s and the value was recorded. After blood was collected, the pig was marked with a livestock chalk marker and released. The snaring method was executed by a trained handler who snared the pig by the snout. Another trained researcher collected approximately 7 ml of blood via jugular venipuncture. Blood was collected into sodium fluoride potassium oxalate tubes (Catalog #: 02-688-48, Fisher Scientific, Pittsburgh, PA) to inhibit further glycolytic metabolism and also into polypropylene serum tubes (Catalog #: 2328, Perfector Scientific, Atascadero, CA). After collection, the plasma in the sodium fluoride potassium oxalate tubes was used to determine LAC of the snared pigs using the same handheld lactate analyzer as used for the sorting board group. After pigs were snared and sampled, they were marked with a livestock chalk marker and released back into the pen. The lactate analyzer was tested with a standard solution to ensure accuracy (CV was 2.8%). The CV reported by the analyzer manufacturer is 3 to 8% depending on the concentration measured.

During blood sampling for both treatment groups, a behavior score of 1 to 4 (1 = no vocalization or movement; 2 = initial vocalization upon boarding; 3 = intermittent movement and vocalization; 4 = constant vocalization and movement, rearing) was assigned to each animal as it was handled. The duration of restraint of the animal was also recorded. To measure duration, time was started when the animal was first touched by the handler and time was stopped upon marking the animal with the livestock chalk marker.

Plasma samples were stored on ice upon collection. After experimentation had concluded, plasma samples were centrifuged for 20 min at 1,200 × g, then stored at −4°F. Serum samples were refrigerated overnight, then centrifuged and stored at the same specifications as plasma.

Blood samples for the laboratory method analysis were collected during exsanguination in the K-State Meat Laboratory. Blood was collected into sodium fluoride potassium oxalate tubes and into polypropylene serum tubes following the same specifications as the restraint methods trial.

Plasma and serum samples collected during exsanguinations were centrifuged at 1,200 × g for 20 min, then stored at −4°F. Blood lactate was determined using three different methods: (1) YSI 2300 Stat Plus Analyzer (YSI Life Sciences, Yellow Springs, OH), which immobilizes lactate oxidase between a polycarbonate membrane and a cellulose membrane, yielding hydrogen peroxide that is measured by a platinum electrode (the amount of hydrogen peroxide corresponds to the LAC amount); (2) a handheld lactate analyzer (Lactate Scout, EKF Diagnostic GmbH, Magdeburg, Germany), which holds a disposable strip that measures LAC in a blood sample ≥0.5 µl and takes up the blood and provides a LAC value in 10 sec; and (3) a lactate assay kit (Eton Bioscience Inc., San Diego, CA) used in an ELISA plate reader (Wallac Victor^2 1420 multilabel counter, International Trading Equipment LTD., Vernon Hills, IL).

Data for blood sampling and restraint were analyzed using a MIXED model procedure in SAS 9.2 (SAS Institute, Inc., Cary, NC) with restraint/sampling treatment as a fixed effect and duration of restraint as a covariate. Individual pig was included as a random effect, and the Kenwardroger approximation was used to calculate denominator degrees of freedom. Pearson correlations also were performed to determine relationships between duration of restraint, behavior score, and LAC. Pig was the experimental unit in all analyses.

Data for laboratory assays were analyzed using a MIXED model procedure in SAS (9.2). Individual pig was included as a random effect, and the Kenwardroger approximation was used to calculate degrees of freedom. Pig was the experimental unit during analyses.

Results and Discussion

The LAC for both blood sampling and restraint methods are shown in Table 1. Also shown are the summary statistics for behavior scores and restraint duration for both methods. Results indicated that pigs restrained with the snaring method had greater ($P = 0.04$) LAC than pigs restrained with the sorting board method. Baseline LAC can range from 2.8 mM (Hamilton et al. 2004[5]) to approximately 4 mM (Benjamin et al. 2001[2]). Baseline LAC is the term used to describe LAC that can be compared across similar treatments. Hamilton et al (2004[5]) reported baseline LAC after snout snaring was 2.8 mM in hogs whose blood was collected via jugular venipuncture. Benjamin et al. (2001[2]) measured LAC after aversive handling of pigs. Baldi et al (1989[8]) suggests that different sampling techniques do not affect plasma parameters because blood metabolites are influenced more by presampling activities than the sampling period itself.

[8] Baldi, A., et al. 1989. Effects of blood sampling procedures, grouping and adrenal stimulation on stress responses in the growing pig. *Reproduction, Nutrition, Développement* 29.1:95.

Relationships were observed between duration of restraint and LAC and behavior in both test groups. A positive correlation was seen between duration of restraint and lactate (r = 0.42, $P = 0.001$) in pigs restrained with a snare; the longer the pig was restrained, the greater the LAC. Positive correlations were observed between duration of restraint and behavior (r = 0.41, $P = 0.001$), duration of restraint and LAC (r = 0.65, $P < 0.001$), and behavior score and LAC (r = 0.26, $P = 0.05$) in the group restrained with sorting boards. Pigs in the sorting board group had higher values of LAC because of longer restraint times. Duration of restraint is a contributor to increased LAC and higher behavior scores in both the sorting board and snaring groups. These results indicate that restraint time should be minimal. Panepinto et al. (1983[9]) evaluated observational stress of a portable sling manufactured from cotton and nylon on Yucatan Miniature Swine. Matte (1999[10]) and Baldi et al. (1989[8]) collected blood samples by catheterization of the jugular vein and jugular venipuncture, respectively, while piglets were in dorsal recumbence; Matte (1999[10]) also utilized the snaring method to collect blood samples from pigs weighing in range from 66 to 220 lb and found that pigs restrained via snout snare exhibited decreased ADG, thereby questioning the efficiency of snaring. These studies encourage simple, quick restraint and sampling methods that reduce the amount of stress placed on the animal. As shown in the present study, when duration of restraint increases, LAC increases in both the snaring and boarding procedures. Longer restraint times and more stressful sampling procedures can significantly affect the outcome of the blood parameter measurements.[9]

In our study, a short restraint duration using the sorting board method could be less stressful than snout snaring if blood sampling and replication are needed. The sorting board method may serve as a replacement for catheterization of the vena cava and jugular venipuncture when repeated lactate sampling is necessary[4]. Regardless of the restraint and sampling methods utilized, duration of restraint should be kept to a minimum to provide for the well-being of the animal. Variation in LAC is possible between swine serum and plasma, so researchers must be aware of the potential drawbacks of analyzing only one medium with one specific method if they desire to compare results.

Blood lactate and its relationship to stress can be measured using a variety of methods. Handheld lactate analyzers have recently been used by researchers to measure LAC because of the speed of results and ease of operation (Edwards, 2010[4]). Results of the laboratory methods analyses indicated that significant variation in LAC values among the three different methods of analysis ($P = 0.001$). A significant difference between LAC also was observed between serum and plasma ($P < 0.0001$). The average values for each method, for both plasma and serum, can be viewed in Table 2. Our data indicate that the value of the concentration can vary with the method of measurement and illustrate a need for further research into what methods are most dependable for measuring LAC in swine. Comparing LAC across studies can be difficult because of the variation in methods of analysis. Studies measuring LAC in swine have utilized handheld lactate analyzers (Edwards, unpublished data; Grandin, 2010[7]), spectrophotometry[3,6] and I-STAT clinical analyzers (Ritter et al. 2009[11]). Several forms of stationary LAC analyz-

[9] Panepinto, L., et al. 1983. A comfortable, minimum stress method of restraint for yucatan Miniature Swine. *Laboratory Animal Science* 33.1:95.
[10] Matte, J. 1999. A Rapid and non-surgical procedure for jugular catheterization of pigs. *Laboratory Animals* 33.3:258.

ers also have been utilized (Hambrecht et al. 2004[3]; Chai et al. 2009[12]; Geesink et al. 2004[13]). In these cases, plasma has been the medium analyzed for LAC, which provides for research to be conducted on LAC in swine serum. In this study, glycolytic potential was inhibited in the tubes from which plasma data were collected. These differences could play a large part in the variations between LAC values in plasma and serum.

Table 1. Mean lactate concentration (LAC), behavior score, and duration of restraint[1]

Item	Mean	Standard deviation	Minimum	Maximum
LAC, mmol				
Snare	2.4	0.73	1.2	5.1
Boarding	2.1	0.79	1.1	6.9
Behavior score[2]				
Snare	2.58	0.50	2	3
Boarding	1.97	0.97	1	4
Restraint duration, sec				
Snare	64.4	36.4	21	192
Boarding	40.6	8.4	28	150

[1] Values represent the mean of 60 pigs per treatment at approximately 165 d of age (278.0 ± 6.4 lb). Pigs were restrained with one of two different methods: snout snare or sorting boards. Blood was drawn and analyzed for LAC; duration of restraint was recorded in seconds.

[2] Behavior score: 1 = no vocalization or movement and 4 = constant movement, vocalization, and struggle

Table 2. Mean lactate concentration (LAC, mmol) in plasma and serum for three different methods of laboratory analysis[1]

Medium	YSI	Handheld	ELISA
Plasma	5.2	6.0	1.8
Serum	6.0	7.6	7.7

[1] Blood samples collected from 120 pigs at approximately 165 d of age (278.0 ± 6.4 lb; n=120 for each method).

[11] Ritter, M. J., M. Ellis, D. B. Anderson, S. E. Curtis, K. K. Keffaber, J. Killefer, F. K. McKeith, C.M Murphy and B. A. Peterson. 2009. Effects of multiple concurrent stressors on rectal temperature, blood acid-base status, and longissimus muscle glycolytic potential in market-weight pigs. J. Anim. Sci. 87:351–362.

[12] Chai, J., Q. Xiong, C. X. Zhang, W. Miao, F. E. Li, R. Zheng, J. Peng and S. W. Jiang. 2010. Effect of pre-slaughter transport on blood constituents and meat quality in halothane genotype of NN Large White x Landrace pigs. Livestock Sci. 127:211–217.

[13] Geesink, G. H., R. G. C. van Buren, B. Savenije, M. W. A. Verstegen, B. J. Ducro, J. G. P. van der Palen, and G. Hemke. 2004. Short-term feeding strategies and pork quality. Meat Sci. 67:1–6.

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