

NON RUMINANT NUTRITION

Evaluation of increased fiber, decreased amino acids, or decreased electrolyte balance as dietary approaches to slow finishing pig growth rates

Emma T. Helm,[†] John F. Patience,[†] Matthew R. Romoser,^{†,‡} Colin D. Johnson,^{†,‡} Jason W. Ross,^{†,‡} and Nicholas K. Gabler^{†,1}

[†]Department of Animal Science, Iowa State University, Ames, IA 50011, USA, [‡]Iowa Pork Industry Center, Iowa State University, Ames, IA 50011, USA

¹Corresponding author: ngabler@iastate.edu

ORCID numbers: 0000-0002-8025-9690 (E. T. Helm); 0000-0002-1672-5116 (J. F. Patience); 0000-0003-1913-3383 (J. W. Ross); 0000-0001-7283-4782 (N. K. Gabler).

Abstract

In swine production, pig movement restrictions or packing plant closures may create the need to slow growth rates of finishing pigs to ensure they remain at a marketable body weight when packing plant access is restored. Although dietary formulations can be successful at slowing pig growth, precision is needed regarding how to best formulate diets to achieve growth rate reductions. Thus, the objective was to evaluate three dietary experimental approaches aimed at slowing growth rates in finishing pigs. These approaches consisted of either increasing neutral detergent fiber (NDF), reducing essential amino acids, or reducing the dietary electrolyte balance through the addition of acidogenic salts. A total of 94 mixed-sex pigs (72.4 ± 11.2 kg BW) across two replicates were individually penned and assigned to 1 of 8 dietary treatments ($n = 11\text{--}12$ pigs/treatment): 1) Control diet representative of a typical corn–soybean meal-based finisher diet (CON); 2) diet containing 15% NDF from soybean hulls (15% NDF); 3) diet containing 20% NDF from soybean hulls (20% NDF); 4) diet containing 25% NDF from soybean hulls (25% NDF); 5) diet formulated as per CON but with 50% of the soybean meal replaced with corn (89% Corn); 6) diet containing 97% corn and no soybean meal or synthetic amino acids (97% Corn); 7) diet containing 2% anhydrous calcium chloride (2% CaCl₂); and 8) diet containing 4% anhydrous calcium chloride (4% CaCl₂). Over 28 d, pig body weights and performance were recorded weekly. At d 28, all pigs were ultrasound scanned and switched to the CON diet to evaluate compensatory gain from d 28 to 35. Overall, increased NDF did not impact any growth performance parameter ($P > 0.05$). Amino acid restriction reduced average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) linearly (linear $P < 0.001$). Similarly, ADG, ADFI, and G:F were linearly reduced with increased CaCl₂ inclusion (linear $P < 0.001$). ADG differed during the compensatory gain period ($P < 0.001$), with 4% CaCl₂-fed pigs having a 47% increase in ADG compared with CON-fed pigs. Conversely, 15% and 25% NDF-fed pigs had reduced ADG compared with CON-fed pigs during the compensatory gain period. Gain efficiency differed from day 28 to 35 ($P < 0.001$), with 4% CaCl₂-fed pigs having a 36% increase in G:F compared with CON-fed pigs. Altogether, these data demonstrate that both amino acid restriction and CaCl₂ inclusion are effective at slowing pig growth, albeit at greater inclusion rates.

Key words: amino acid restriction, appetite, compensatory gain, fiber, growth, swine

Abbreviations

AA	amino acid
ADF	acid detergent fiber
ADFI	average daily feed intake
ADG	average daily gain
BW	body weight
dEB	dietary electrolyte balance
EAA	essential amino acid
G:F	gain:feed
ME	metabolizable energy
NDF	neutral detergent fiber
NE	net energy
SID	standardized ileal digestible
STTD	standardized total tract digestible
TSAA	total sulfur amino acids

Introduction

The COVID-19 pandemic has provided significant and unique challenges to the United States swine industry, which observed massive complications associated with supply chain disruptions and reduced packing plant capacity (Hahn et al., 2020; Shi et al., 2021).

Packing plant closures quickly caused an accumulation of market-ready pigs that were unable to be harvested. In order to avert mass euthanasia, producers sought alternative strategies such as novel dietary formulations to slow growth rates and maintain pig body weight within an acceptable range until packing plant capacity was restored (Tokach et al., 2021). Although many of the complications associated with 2020 packing plant closures have since been resolved, they revealed a critical need for the swine industry to be better prepared to respond to future supply chain disruptions, such as future pandemics or the emergence of a foreign animal disease like African Swine Fever in the United States (Sandra et al., 2020).

Although several hypothetically valid dietary approaches to slow pig growth rates were suggested as potentially feasible during spring 2020 (Patience and Greiner, 2020), these nutritional strategies were scientifically unproven. Suggested strategies included increasing dietary neutral detergent fiber (NDF) to lower caloric density, reducing the concentration of lysine and other essential amino acids (EAAs) to suppress protein accretion and thus feed intake, and reducing the dietary electrolyte balance (dEB) through the addition of an acidogenic salt to alter acid-base homeostasis and thus reduce feed intake. Unfortunately, as slowing growth rates is largely converse to typical aims of pork producers, very little data were available regarding which dietary strategies worked best to slow growth rates. Since then, several groups have provided research demonstrating these strategies to be successful at slowing growth rates (Helm et al., 2021; Rao et al., 2021). Our group previously evaluated several experimental approaches including high NDF, amino acid restriction, and acidogenic salt inclusion at a single level and determined all three to be effective at slowing growth (Helm et al., 2021). However, as this work only evaluated a single level of each experimental approach, better precision is needed to understand which levels of various approaches are successful at slowing growth rates. Therefore, the objective of this experiment was to evaluate independent dietary approaches intended to slow pig growth and/or reduce feed intake. This experiment made use of three potential experimental approaches (increasing dietary NDF, amino acid restriction, and inclusion

of an acidogenic salt) at several different levels to increase precision of dietary formulations intended to slow growth rates. We hypothesized that diet formulations that increased NDF above 15%, contained increasing amounts of an acidogenic salt, or restricted EAAs would attenuate finishing pig growth rates.

Materials and Methods

All animal procedures were approved by the Iowa State University Institutional Animal Care and Use Committee (IACUC protocol #20-057) and adhered to the guidelines for the ethical and humane use of animals for research according to the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010).

Animals, housing, and experimental design

Across 2 replicates, a total of 94 barrows and gilts (72.4 ± 11.2 kg BW; Camborough [1,050] \times 337) were individually penned and assigned to 1 of 8 dietary treatments ($n = 11$ – 12 pigs/treatment). Pigs were fed experimental diets for 28 days. Individual pig body weights and feed disappearance were recorded at days 0, 7, 14, 21, and 28 to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain efficiency (gain:feed, G:F). On day 28, all pigs were switched from their respective experimental diet to the CON diet to evaluate compensatory gain in the following 7 days (day 28–35). Individual pig body weights and feed disappearance at day 28 and 35 were used to calculate ADG, ADFI, and G:F in the compensatory gain period.

Diets and dietary treatments

Diet formulations are presented in Table 1, along with calculated nutrient composition in Table 2. Regardless of dietary treatment, pigs received their diets ad libitum and had free access to water at all times. The Control (CON) diet was formulated as a traditional corn-soybean meal-based diet that met or exceeded all nutrient requirements for this size of finishing pig (National Research Council, 2012). The following dietary treatments represented three experimental approaches to slow pig growth rates. The first approach increased NDF content of the diets from ~9.5% (CON) to 15% (15% NDF), 20% (20% NDF), and 25% (25% NDF) by increasing the inclusion rate of soy hulls (12.5%–33.2% of diet in diets 2–4, respectively) thus lowering diet bulk density and impairing the pig's ability to achieve its desired daily energy intake (Mauch et al., 2018). Amino acids were held constant and kept equivalent to the CON diet, but dietary ME decreased as dietary fiber increased. This approach was taken to ensure that amino acid supply would not impair pig performance and thus confound the outcome of the experiment. The second approach reduced dietary EAA concentrations (treatments #5 and #6). This was achieved through the complete (97% Corn) or 50% (89% Corn) removal of soybean meal and synthetic amino acids from the CON diet formulation and adding this quantity back as corn. In both these diets, vitamins, minerals, and ME were formulated to be the same as the CON diet. The third approach involved reduction of dEB through addition of an acidogenic salt, calcium chloride (Patience et al., 1987). dEB was calculated as $\text{Na}^+ + \text{K}^+ - \text{Cl}^-$ and expressed in mEq/kg. These diets were formulated to contain 2% (2% CaCl_2) or 4% (4% CaCl_2) anhydrous calcium chloride. This resulted in a 3.7- and 6.4-fold increase in chloride, and a lowering of dEB

Table 1. Ingredient composition of experimental diets, as fed

Ingredients (%)	CON	15% NDF	20% NDF	25% NDF	89% Corn	97% Corn	2% CaCl ₂	4% CaCl ₂
Corn	80.98	69.75	60.42	51.69	89.06	97.13	78.29	75.59
Soybean meal, 47% CP	16.03	14.92	14.43	13.3	8.02	–	16.22	16.41
Limestone	1.16	1.01	0.87	0.73	1.20	1.23	0.74	0.31
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.35	0.20
Soybean oil	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-lysine HCl	0.25	0.25	0.24	0.25	0.13	–	0.25	0.25
DL-methionine	0.01	0.03	0.04	0.06	0.01	–	0.02	0.02
L-threonine	0.06	0.06	0.07	0.08	0.03	–	0.06	0.06
L-tryptophan	0.01	0.01	0.01	0.02	0.01	–	0.01	0.01
Monocalcium phosphate, 21%	0.13	0.11	0.14	0.18	0.20	0.27	0.07	–
Vitamin premix ¹	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral premix ²	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase ³	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Soybean hulls	–	12.50	22.42	32.33	–	–	–	–
Monosodium phosphate ⁴	–	–	–	–	–	–	1.15	2.30
Anhydrous calcium chloride ⁴	–	–	–	–	–	–	2.00	4.00

¹Provided per kilogram of diet: 6,125 IU vitamin A, 700 IU vitamin D₃, 50 IU vitamin E, 30 mg vitamin K, 0.05 mg vitamin B₁₂, 11 mg riboflavin, 56 mg niacin, and 27 mg pantothenic acid.

²Provided per kilogram of diet: 22 mg Cu (as CuSO₄), 220 mg Fe (as FeSO₄), 0.4 mg I (as Ca(IO₃)₂), 52 mg Mn (as MnSO₄), 220 mg Zn (as ZnSO₄), and 0.4 mg Se (as Na₂SeO₃).

³Optiphos 5000, Huvepharma, Peachtree City, GA. Minimum activity of 500 FTU/kg complete feed.

⁴Nutra Blend, Neosho, MO.

Table 2. Calculated energy and nutrient composition of experimental diets, as fed

Item ¹	CON	15% NDF	20% NDF	25% NDF	89% Corn	97% Corn	2% CaCl ₂	4% CaCl ₂
ME, Mcal/kg	3.32	3.14	3.00	2.86	3.33	3.34	3.24	3.15
NE, Mcal/kg	2.54	2.34	2.18	2.02	2.59	2.63	2.47	2.40
Crude protein, %	14.33	14.16	14.18	13.94	11.17	8.00	14.20	14.07
Ether extract, %	3.56	3.32	3.11	2.92	3.72	3.88	3.47	3.38
NDF, %	8.69	15.00	20.00	25.00	8.77	8.85	8.46	8.23
ADF, %	3.18	7.99	11.82	15.62	2.99	2.80	3.11	3.04
SID Lys, %	0.77	0.77	0.77	0.77	0.48	0.18	0.77	0.77
SID Met, %	0.23	0.23	0.24	0.24	0.19	0.15	0.23	0.23
SID Cys + Met, %	0.44	0.44	0.44	0.44	0.37	0.29	0.44	0.44
SID TSAA:Lys	0.58	0.57	0.57	0.57	1.11	1.63	0.58	0.57
SID Thr, %	0.48	0.48	0.48	0.48	0.35	0.21	0.48	0.48
SID Thr:Lys	0.63	0.62	0.62	0.62	0.90	1.17	0.63	0.62
SID Trp, %	0.14	0.14	0.14	0.14	0.10	0.05	0.14	0.14
SID Trp:Lys	0.18	0.18	0.18	0.18	0.22	0.26	0.18	0.18
Ca, %	0.54	0.54	0.54	0.54	0.54	0.54	1.05	1.55
P Total, %	0.49	0.48	0.47	0.46	0.48	0.47	0.76	1.02
STTD P, %	0.27	0.27	0.27	0.27	0.27	0.27	0.52	0.78
Ca:STTD P	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Na, %	0.23	0.22	0.22	0.22	0.23	0.22	0.39	0.55
K, %	0.39	0.36	0.34	0.32	0.21	0.30	0.39	0.39
Mg, %	0.16	0.14	0.13	0.11	0.15	0.14	0.15	0.14
Cl, %	0.41	0.40	0.40	0.39	0.38	0.34	1.53	2.64
Elemental sulfur, %	0.16	0.16	0.17	0.17	0.14	0.11	0.16	0.16
dEB, mEq/kg	85	75	70	68	47	77	–161	–404

¹ME, metabolizable energy; NE, net energy; NDF, neutral detergent fiber; ADF, acid detergent fiber; SID, standardized ileal digestible; TSAA, total sulfur amino acids; STTD, standardized total tract digestible; dEB, dietary electrolyte balance.

by 246 and 489 mEq/kg, respectively, compared with the CON diet. Due to the concurrent addition of calcium with chloride, ammonium phosphate was added to the diet to maintain a constant Ca to standardized total tract digestible (STTD) P ratio, to ensure that changes in this ratio did not confound experimental results.

Backfat depth and loin muscle area

On day 28, live animal real-time ultrasound measurements were taken at the 10th rib to determine backfat thickness and loin muscle area. Ultrasound images were captured using a portable ExaGo scanner (Echo Control Medical, Angoulême, France) and interpreted by a National Swine Improvement Federation

certified ultrasound technician and were used as an objective evaluation of body composition regardless of animal weight, treatment, and diet. Backfat depth and loin muscle area are presented in mm and cm², respectively.

Statistical analysis

Statistical analysis of all data was performed using SAS (version 9.4; SAS Inst. Inc., Cary, NC). The following mixed model was fitted to growth performance parameters with pig as the experimental unit:

$$Y_{ijk} = \mu + \text{Diet}_i + \text{Rep}_j + e_{ijk},$$

wherein Y_{ijk} is the phenotypic observation measured on pig k ; μ is the overall mean; Diet_i is the effect of dietary treatment (fixed effect); Rep_j is the effect of experimental repetition (random effect); and e_{ijk} is the error term of pig k subjected to treatment i in repetition j , $e_{ijk} \sim N(0, \sigma_e^2)$. Orthogonal polynomial contrasts were performed within each dietary approach (NDF, AA restriction, or CaCl₂) to test the linear effects of treatment level on selected response variables. This approach was adopted because there was no desire to compare experimental approaches to reduce feed intake and/or growth rate, but rather to investigate which of the three approaches, independent of each other, would achieve our objectives. To investigate the overall relationship between body weight and ultrasound measurements irrespective of treatment, all treatment groups were included in simple linear regression analysis analyzing the relationship between ultrasound parameters (BF, LMA) and day 28 body weight. All data are presented as least squares means with a pooled standard error. Differences were considered significant when $P < 0.05$ and a tendency when $0.05 \leq P \leq 0.10$.

Results and Discussion

Approach 1: increased NDF

Dietary fiber consists of carbohydrate components that are unable to be hydrolyzed by host endogenous enzymes, but can be fermented to varying degrees by the gastrointestinal microbiota (AACC, 2001). The NDF fraction includes cellulose, hemicellulose, and lignin, compounds which are relatively resistant to host degradation and microbial fermentation (National Research Council, 2012). Thus, diets high in NDF are generally associated with reductions in digestibility, pig performance, and carcass yield (Weber et al., 2010, 2015; Mauch et al., 2018). However, due to the increased digesta volume associated with high fiber diets, they are frequently regarded as satiating despite their lower energy density (Kerr and Shurson, 2013). In the current experiment, dietary NDF was increased by the inclusion of soybean hulls. There were only marginal impacts of this experimental approach on ADG, ADFI, or G:F during any individual week of the 28 day period in which experimental diets were fed, even when NDF was increased to 25% (Table 3). There was a tendency for reduced growth rates (Linear $P = 0.086$) in the first 7 days on feed; however, afterwards pigs appeared to adapt and grow similarly to their counterparts fed a lower fiber diet. Similarly, overall 28 day ADFI and G:F did not differ; however there was a tendency for reduced ADG as dietary NDF increased (linear $P = 0.054$). This is in contrast with previous work wherein both 20% (Helm et al., 2021) and 25% (Mauch et al., 2018) NDF have proven sufficient to slow growth rates. The minimal responses observed herein may be partially attributed to the smaller sample size in the current study (11–12 pigs per treatment) and greater variability. However, as the

Table 3. Impact of increased NDF on growth performance and ultrasonically determined carcass composition

	NDF				SEM	P-values	
	CON 8.7%	15%	20%	25%		NDF ¹	Linear ²
Day 0–7							
ADG, kg/d	1.33	0.88	1.05	0.89	0.147	0.127	0.086
ADFI, kg/d	2.64	2.48	2.49	2.30	0.357	0.495	0.152
G:F	0.51	0.37	0.43	0.40	0.105	0.331	0.273
Day 8–14							
ADG, kg/d	1.05	1.25	0.98	1.00	0.176	0.290	0.417
ADFI, kg/d	3.00	2.90	2.82	2.74	0.402	0.652	0.207
G:F	0.35	0.45	0.34	0.38	0.034	0.082	0.815
Day 15–21							
ADG, kg/d	1.17	0.90	1.11	1.06	0.099	0.104	0.639
ADFI, kg/d	2.84	2.80	2.96	2.86	0.476	0.942	0.810
G:F	0.40	0.34	0.42	0.38	0.035	0.229	0.986
Day 22–28							
ADG, kg/d	0.83	1.13	1.03	0.65	0.166	0.175	0.386
ADFI, kg/d	2.74	2.84	2.85	2.50	0.291	0.638	0.472
G:F	0.32	0.37	0.26	0.30	0.103	0.562	0.527
Overall (day 0–28)							
Day 0 BW, kg	75.3	71.6	72.6	72.3	3.46	0.883	0.597
Day 28 BW, kg	104.9	104.3	100.7	97.6	4.12	0.542	0.161
ADG, kg/d	1.06	1.13	1.00	0.90	0.076	0.121	0.054
ADFI, kg/d	2.80	2.96	2.78	2.6	0.415	0.259	0.159
G:F	0.38	0.39	0.39	0.35	0.044	0.560	0.252
Day 28 ultrasound							
Backfat, mm	13.8	14.4	11.7	11.1	1.35	0.111	0.033
Loin muscle area, cm ²	46.5	44.2	44.8	41.7	1.65	0.215	0.060

¹P-value for overall effect of NDF.

²P-value for the linear effect of NDF.

ability to digest and utilize fiber ingredients for growth depends heavily on the endogenous microbiota (Cheng et al., 2018; Pu et al., 2020), it is also possible differences in microbial capacity for fiber degradation contributed to the minimal responses in the current study.

Although only marginal reductions in growth were observed due to increasing NDF, at day 28 there was a linear decrease in ultrasound backfat depth with increased dietary NDF ($P = 0.033$; Table 3). Additionally, a tendency for a linear reduction in ultrasound loin muscle area was observed as dietary NDF increased ($P = 0.060$) suggesting that while although NDF did not significantly slow growth rates, it did alter carcass composition in ways typically associated with reduced daily caloric intake (Beaulieu et al., 2009). High NDF diets are known to increase gut fill (Asmus et al., 2014) which would reduce carcass size without being reflected in live animal performance (Soto et al., 2019). Thus, results of the current experiment would suggest that while although increased NDF does not significantly slow pig growth rates, carcass weight gain, and dressing percentage may be reduced. This could have negative implications on profitability, particularly if producers are paid on a carcass weight basis.

Approach 2: amino acid restriction

Restricting essential or total amino acids is a simple and inexpensive approach to reduce the capacity for lean tissue accretion (Kerr et al., 1995; Ruusunen et al., 2007). In the current experiment, total amino acids and protein were restricted through partial (89% Corn) or complete (97% Corn) removal of soybean meal and synthetic amino acids from the diet. In the current experiment, both ADG and G:F were consistently reduced as EAA levels decreased in the diet (Table 4). ADG was linearly reduced by EAA levels at day 7, 14, 21, and 28 (linear $P \leq 0.009$). Similarly, G:F was linearly reduced by EAA levels at day 7, 14, and 21 (linear $P \leq 0.002$) and tended to be reduced at day 28 (linear $P = 0.097$). ADFI was not reduced by EAA levels at day 7, but was reduced at day 14, 21, and 28 (linear $P \leq 0.043$).

Previously, complete removal of soybean meal and synthetic amino acids has been shown to slow growth rates 44%–55% when fed for either 16 (Rao et al., 2021) or 42 days (Helm et al., 2021), while partial removal slowed growth 15% over 28 days (Rao et al., 2021). Similarly, we observed ADG over the 28 d study period to be reduced with increased corn inclusion (linear $P < 0.001$). Overall ADG was 59% lesser in 97% corn-fed pigs compared with CON-fed pigs and 39% lesser in 97% corn-fed pigs compared with 87% corn-fed pigs (treatment $P < 0.001$). As a result, 97% corn-fed pigs were 22.9 kg lighter than CON-fed pigs after 28 days ($P < 0.001$; Figure 2), confirming that amino acid restriction successfully limits capacity for growth. However, amino acid restriction may or may not reduce feed intake compared with pigs fed diets of adequate amino acid concentrations (Helm et al., 2021; Rao et al., 2021). In the current experiment, overall ADFI was reduced (linear $P = 0.002$), being 19% lesser in the 97% corn-fed pigs compared with CON-fed pigs and 87% corn-fed pigs (treatment $P < 0.001$). This suggests that perhaps severe, but not moderate, amino acid restriction reduces feed intake, albeit to a lesser degree than it reduces growth. As the reduction in feed intake was lesser than the observed reduction in growth, gain efficiency was reduced 16% in 89% corn-fed pigs compared with CON-fed pigs, and was reduced 50% in 97% corn-fed pigs compared with CON-fed pigs ($P < 0.001$). Although the observed sub-optimal feed efficiency would not be economical during normal market conditions (Rao et al., 2021), during abnormal market conditions the efficacy, simplicity, and low-cost of this approach likely far outweighs

Table 4. Impact of amino acid and protein restriction on growth performance and ultrasonically determined carcass composition

	Corn ¹			SEM	P-values	
	CON 80.9%	89%	97%		Corn ²	Linear ³
Day 0–7						
ADG, kg/d	1.33 ^a	0.97 ^a	0.39 ^b	0.153	<0.001	<0.001
ADFI, kg/d	2.64	2.71	2.35	0.476	0.145	0.148
G:F	0.51 ^a	0.37 ^{ab}	0.19 ^b	0.101	0.003	0.001
Day 8–14						
ADG, kg/d	1.05 ^a	0.91 ^a	0.53 ^b	0.211	0.001	<0.001
ADFI, kg/d	3.00 ^a	2.91 ^a	2.33 ^b	0.433	0.001	0.001
G:F	0.35 ^a	0.31 ^{ab}	0.22 ^b	0.041	0.007	0.002
Day 15–21						
ADG, kg/d	1.17 ^a	0.89 ^b	0.45 ^c	0.177	<0.001	<0.001
ADFI, kg/d	2.84 ^{ab}	3.12 ^a	2.31 ^b	0.642	0.007	0.043
G:F	0.40 ^a	0.29 ^b	0.18 ^c	0.022	<0.001	<0.001
Day 22–28						
ADG, kg/d	0.83 ^a	0.76 ^{ab}	0.43 ^b	0.105	0.017	0.009
ADFI, kg/d	2.74	2.49	2.19	0.348	0.103	0.035
G:F	0.32	0.29	0.19	0.061	0.099	0.097
Overall (day 0–28)						
Day 0 BW, kg	75.3	72.7	69.8	4.16	0.522	0.260
Day 28 BW, kg	104.9 ^a	97.4 ^a	82.0 ^b	6.23	0.001	<0.001
ADG, kg/d	1.06 ^a	0.88 ^a	0.43 ^b	0.097	<0.001	<0.001
ADFI, kg/d	2.80 ^a	2.81 ^a	2.26 ^b	0.475	0.002	0.002
G:F	0.38 ^a	0.32 ^b	0.19 ^c	0.024	<0.001	<0.001
Day 28 ultrasound						
Backfat, mm	13.8	12.9	12.6	1.22	0.971	0.831
Loin muscle area, cm ²	46.5 ^a	41.3 ^{ab}	36.6 ^b	1.72	0.001	<0.001

¹Amino acid restriction was achieved by the 50% (89% Corn) or complete (97% Corn) removal of soybean meal from the control (CON) diet formulation and adding this quantity back in as corn.

²P-value for overall effect of amino acid restriction.

³P-value for the linear effect of amino acid restriction.

^{a,b,c}Means with differing superscripts differ at $P < 0.05$.

any concerns associated with poor feed efficiency (Norton et al., 2020).

As amino acid restriction limits capacity for protein accretion, an increase in carcass backfat is often observed (Kerr et al., 1995; Ruusunen et al., 2007; Helm et al., 2021; Rao et al., 2021). In the current experiment, day 28 ultrasound backfat depth was not impacted by decreased EAA levels (treatment $P = 0.971$; linear $P = 0.831$). This may be due to the relatively short duration of the restriction period, and perhaps changes to backfat depth would have been observed given a longer feeding period. However, loin muscle area was reduced linearly with decreased EAA levels (linear $P < 0.001$), being 10 cm² smaller in the 97% corn-fed pigs compared with CON-fed pigs ($P = 0.001$). Although this may suggest a reduction in carcass cutability and size, it is most likely that these changes were simply a consequence of lower body weight at the time ultrasounds were recorded; these measurements were taken on a fixed time basis rather than a fixed weight basis. Indeed, loin muscle area had a moderate, positive relationship to day 28 body weight ($R^2 = 0.605$; $P < 0.001$; Figure 1). Taken together, both moderate and severe amino acid restriction successfully slowed growth rates to varying degrees with marginal impact on live animal body composition after 28 days, reemphasizing the importance of this approach.

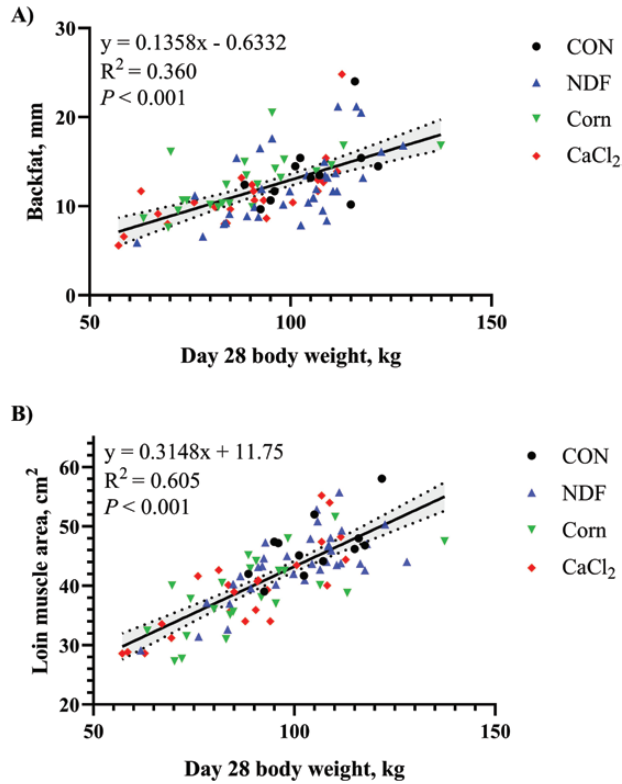


Figure 1. Relationships between day 28 body weight and (A) day 28 backfat and (B) day 28 loin muscle area. Data points represent individual pigs.

Approach 3: reducing dEB

Reducing dEB through the addition of CaCl_2 was the most technically challenging approach investigated. dEB is calculated by summing the charges contributed by the monovalent ions sodium, potassium, and chloride, and represents one source of acid contributed by the diet (Patience and Chaplin, 1997), where a lesser dEB represents a more acidogenic diet. As acids are also generated through metabolism, lowering the dEB increases the acid load experienced by the pig, which typically leads to acidosis and appetite suppression (Yen et al., 1981; Patience et al., 1987). The mode of action has been shown to be unrelated to taste, but is rather a metabolic effect (Patience and Wolynetz, 1990), possibly involving glucose transport and post-translational regulation of leptin secretion (Teta et al., 2003).

In the current study, inclusion of either 2% or 4% CaCl_2 increased dietary chloride content 3.7- or 6.4-fold, respectively, and reduced dEB from 85 to -161 or -404 mEq/kg, respectively. Previously, growth rate reductions have been observed resulting from CaCl_2 inclusion (Yen et al., 1981; Patience et al., 1987; Haydon et al., 1990; Dersjant-Li et al., 2001; Helm et al., 2021), although the extent of this depends on CaCl_2 inclusion rate. In the current experiment, increased CaCl_2 inclusion reduced ADG linearly at day 7, 14, 21, and 28, and for the overall feeding period (linear $P \leq 0.032$; Table 5). Overall ADG was reduced 73% in 4% CaCl_2 -fed pigs compared with 2% CaCl_2 -fed pigs and 77% reduced in 4% CaCl_2 -fed pigs compared with CON-fed pigs ($P < 0.001$). Although this response was linear, the difference between 2% and 4% CaCl_2 diets was far greater than the difference between the 2% CaCl_2 and control diets. In fact, the 4% CaCl_2 almost stopped growth entirely, as pigs gained only 0.24 kg/d throughout the entire

Table 5. Impact of increased calcium chloride on growth performance and ultrasonically determined carcass composition

	Calcium chloride (CaCl_2) ¹			SEM	P-values	
	CON 0%	2%	4%		CaCl_2 ²	Linear ³
Day 0–7						
ADG, kg/d	1.33 ^a	0.80 ^a	-0.08 ^b	0.180	<0.001	<0.001
ADFI, kg/d	2.64 ^a	2.45 ^a	1.53 ^b	0.347	<0.001	<0.001
G:F	0.51 ^a	0.32 ^{ab}	-0.12 ^b	0.156	0.018	0.006
Day 8–14						
ADG, kg/d	1.05 ^a	1.10 ^a	0.16 ^b	0.178	<0.001	<0.001
ADFI, kg/d	3.00 ^a	2.79 ^a	1.61 ^b	0.263	<0.001	<0.001
G:F	0.35 ^a	0.33 ^a	0.06 ^b	0.079	0.009	0.005
Day 15–21						
ADG, kg/d	1.17 ^a	1.10 ^a	0.25 ^b	0.158	<0.001	<0.001
ADFI, kg/d	2.84 ^a	2.95 ^a	1.26 ^b	0.494	<0.001	<0.001
G:F	0.40	0.37	0.27	0.067	0.302	0.137
Day 22–28						
ADG, kg/d	0.83 ^{ab}	0.99 ^a	0.43 ^b	0.138	0.014	0.032
ADFI, kg/d	2.74 ^a	2.95 ^a	1.28 ^b	0.338	<0.001	<0.001
G:F	0.32	0.34	0.57	0.169	0.343	0.178
Overall (day 0–28)						
Day 0 BW, kg	75.3	73.0	72.3	3.55	0.747	0.471
Day 28 BW, kg	104.9 ^a	98.3 ^a	79.1 ^b	5.44	<0.001	<0.001
ADG, kg/d	1.06 ^a	0.90 ^a	0.24 ^b	0.097	<0.001	<0.001
ADFI, kg/d	2.80 ^a	2.73 ^a	1.42 ^b	0.357	<0.001	<0.001
G:F	0.38 ^a	0.33 ^a	0.15 ^b	0.036	<0.001	<0.001
Day 28 ultrasound						
Backfat, mm	13.8 ^a	13.1 ^a	9.4 ^b	1.71	0.006	0.003
Loin muscle area, cm ²	46.5 ^a	42.9 ^a	36.3 ^b	1.78	0.001	<0.001

¹The acidogenic salt calcium chloride (CaCl_2) was added to the control (CON) diet formulation at either 2% or 4%.

²P-value for overall effect of CaCl_2 .

³P-value for the linear effect of CaCl_2 .

^{a,b}Means with differing superscripts differ at $P < 0.05$.

feeding period compared with the 1.06 kg/d achieved by the pigs on the control diet.

As CaCl_2 slows growth rates via appetite suppression, reductions in ADFI are associated with this approach (Yen et al., 1981). Indeed, in the current experiment, we observed ADFI was reduced linearly as CaCl_2 inclusion increased at day 7, 14, 21, and 28, and the overall period (linear $P < 0.001$ for all; Table 5). Overall ADFI was reduced 48% in 4% CaCl_2 -fed pigs compared with 2% CaCl_2 -fed pigs and was reduced 50% in 4% CaCl_2 -fed pigs compared with CON-fed pigs ($P < 0.001$). Further, gain efficiency was also impacted by this approach. Gain efficiency was linearly reduced at day 7 and 14 (linear $P \leq 0.006$) but not at day 21 or 28 (linear $P \geq 0.137$). Overall gain efficiency was reduced 55% in 4% CaCl_2 -fed pigs compared with 2% CaCl_2 -fed pigs and was reduced 85% in 4% CaCl_2 -fed pigs compared with CON-fed pigs ($P < 0.001$).

Both ultrasound backfat depth and loin muscle area were linearly reduced with increased CaCl_2 inclusion (linear $P \leq 0.003$). Backfat depth was reduced 32% in 4% CaCl_2 -fed pigs compared with CON pigs ($P = 0.006$) and loin muscle area was reduced 22% in 4% CaCl_2 -fed pigs compared with CON pigs (10 cm² difference; $P = 0.006$). This is consistent with previous work reporting reduced carcass backfat and loin muscle depth in pigs fed 3% CaCl_2 (Helm et al., 2021). It is likely these changes were due to

the smaller body weight of these pigs, as day 28 body weight of 4% CaCl₂-fed pigs was 25.8 kg lower than that of CON-fed pigs ($P < 0.001$) and was only 6.8 kg greater than their average body weight at day 0 (Figure 2). Had these pigs been allowed to achieve equivalent body weight, it is possible these differences in ultrasound composition may have been remedied; however further experimentation would be needed to validate this posit.

Although CaCl₂ addition provided the greatest reductions in growth rates, it may be more costly than amino acid restriction when corn ingredients are readily available. Further, due to the concurrent addition of calcium with chloride, ammonium phosphate was added to the diet to maintain a constant Ca:STTD P ratio. This was done to ensure that changes in this ratio did not confound experimental results, as excess calcium has been shown to impair phosphorus absorption and adversely affect growth (Cromwell, 2005). Although this precaution was necessary from an experimental standpoint, it significantly increased the cost of the diet due to the price of phosphorus, which would make this approach even more cost prohibitive. However, balancing Ca:STTD P may not be needed in commercially formulated diets, intended for relatively short-term feeding, as we successfully fed pigs a 3% CaCl₂ diet for 42 days without rebalancing Ca:STTD P ratios and observed similar results to what is reported herein (Helm et al., 2021). Removal of ammonium phosphate from this formulation would make this approach more economically viable in commercial practice, particularly if almost complete cessation

of growth is desired. An alternative solution would be to employ ammonium chloride rather than calcium chloride, thus eliminating the issue of rebalancing Ca:STTD P ratios altogether (Boles et al., 1994). As a note of caution, acidogenic diets are not recommended for feeding to replacement breeding stock due to possible negative impacts on skeletal development (Darriet et al., 2017).

Compensatory gain

An additional facet of diets intended to slow growth is the potential to observe compensatory gain after pigs are switched back to a normal diet. Compensatory gain can be defined as a period of accelerated growth in pigs after nutrient restriction (Critser et al., 1995). This may or may not be beneficial, depending on the dietary scenario under which growth restriction occurs and the need and time frame desired for pigs to obtain extra body weight. In the current experiment, we evaluated compensatory gain in the week following the experimental diet period. After 28 days of feeding experimental diets, all pigs were fed the CON diet to examine compensatory gain from day 28 to 35 (Table 6). ADG differed ($P < 0.001$), with 4% CaCl₂-fed pigs having a 47% increase in ADG compared with CON-fed pigs. ADFI did not differ during the compensatory gain period ($P = 0.518$). Gain efficiency differed from day 28 to 35 ($P < 0.001$), with 4% CaCl₂-fed pigs having a 57% increase in G:F compared with CON-fed pigs. At day 35, 97% Corn-fed pigs and 4% CaCl₂-fed pigs still had

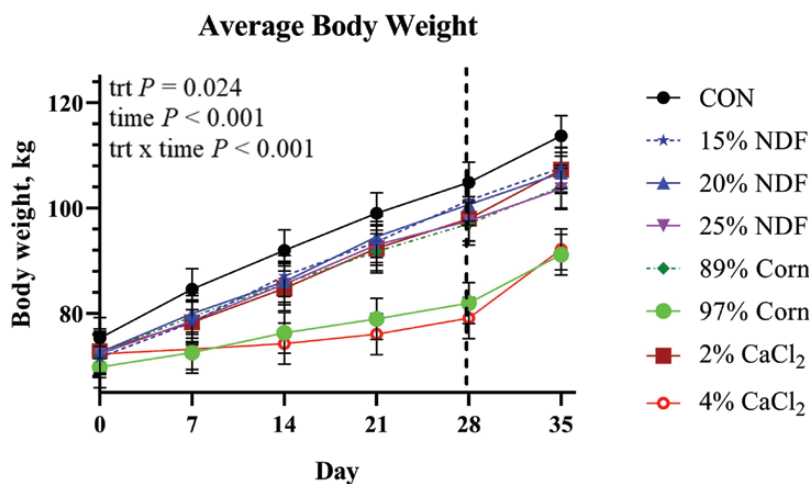


Figure 2. Average body weights of pigs fed diets intended to slow growth. Three experimental approaches were utilized to slow finishing pig growth including increasing NDF (15%, 20%, and 25% NDF), restricting amino acids via removal of soybean meal (88% and 97% Corn), and through inclusion of CaCl₂, an acidogenic salt (2% and 4% CaCl₂). Diets were fed for 28 d, after which all pigs were switched to the control (CON) diet to investigate the potential for compensatory gain (denoted by dotted line) from d 28 to 35.

Table 6. Impact of diets intended to slow growth on compensatory gain day 28–35¹

Item	CON	15% NDF	20% NDF	25% NDF	89% Corn	97% Corn	2% CaCl ₂	4% CaCl ₂	SEM	P-value
Day 28 BW, kg	104.9 ^a	104.6 ^a	100.7 ^a	97.6 ^{ab}	97.4 ^{ab}	82.0 ^{bc}	98.4 ^{ab}	79.1 ^c	5.70	<0.001
Day 35 BW, kg	113.7 ^a	110.9 ^a	106.7 ^{ab}	103.7 ^{ab}	104.6 ^{ab}	91.2 ^b	107.8 ^{ab}	92.2 ^b	7.19	0.001
ADG, kg/d	1.27 ^{bc}	0.90 ^{bc}	0.86 ^c	0.87 ^c	1.03 ^{bc}	1.31 ^b	1.24 ^{bc}	1.87 ^a	0.292	<0.001
ADFI, kg/d	4.24	4.03	3.99	4.27	3.93	4.28	4.42	4.00	0.622	0.518
G:F	0.30 ^b	0.22 ^b	0.20 ^b	0.20 ^b	0.26 ^b	0.30 ^b	0.30 ^b	0.47 ^a	0.033	<0.001

¹Three experimental approaches were utilized to slow finishing pig growth including increasing NDF (15%, 20%, and 25% NDF), restricting amino acids via removal of soybean meal (89% and 97% Corn), and through inclusion of CaCl₂, an acidogenic salt (2% and 4% CaCl₂). Diets were fed for 28 d, after which all pigs were switched to the control (CON) diet to investigate compensatory gain from d 28 to 35.

^{a,b,c}Means with differing superscripts differ at $P < 0.05$.

reduced body weights compared with CON-fed pigs (22.5 and 21.5 kg, respectively; $P = 0.001$).

The observed compensatory gain in CaCl₂-fed pigs was likely a result of both increased feed efficiency resulting from their smaller size, as well as greater gastrointestinal fill. While 97% corn-fed pigs were also at a smaller body size, no compensatory gain was observed in this group. This contradicts previous work, where compensatory gain was observed in pigs after pigs were fed a similarly formulated amino acid-restricted diet (Rao et al., 2021) but agrees with research reported by Norton et al. (2020). This may be due to differences in pig genetics, growth stage, or feeding period duration, all of which may influence the observance of compensatory gain after protein restriction (Menegat et al., 2020). Interestingly, high NDF-fed pigs actually had reduced ADG during the 7 d compensatory period. This further supports the postulation that compared with the CON-fed pigs, the NDF-fed pigs had greater gastrointestinal fill during the experimental period (Asmus et al., 2014), the loss of which during the compensatory period may have contributed to the reductions in growth rate observed. It is also possible that the pig and its endogenous microbiota had become adapted to the high fiber diet, and were less able to utilize a lower fiber (higher starch) diet formulations (Cheng et al., 2018; Pu et al., 2020).

Conclusions

In order to be better prepared for future scenarios that might interrupt the flow of pigs to packing plants, pork producers need a better understanding of dietary formulations designed to slow growth or reduce feed intake of finishing pigs. The results of this study provide further evidence that several dietary strategies successfully slow finishing pig growth, particularly 4% CaCl₂ (reduced dEB) and 97% Corn (reduced EAA). The 4% CaCl₂ diet was the most effective at slowing growth rates, nearly arresting growth over the 28-day study (Figure 2). Thus, this dietary strategy is likely best for producers requiring dramatic intervention and growth cessation. The 97% corn diet was highly successful at slowing growth rates, and would be an inexpensive and simple dietary option for producers that need to slow growth rates. Regardless, either dietary option would work for producers depending on the specific situation and economics of feed ingredients. Further, improved understanding of how compensatory gain is affected by different growth limiting approaches may allow for greater precision in targeting market body weights during scenarios in which the marketing window is restricted.

Acknowledgments

Funding for this research was provided by the Iowa State University Iowa Pork Industry Center Emergency Research Fund. *Conflict of interest statement.* All authors declare no conflict of interest.

Literature Cited

AACC. 2001. *The definition of dietary fiber*. American Association of Cereal Chemists. *Cereal Foods World* 46:112–126.

Asmus, M., J. DeRouchey, M. Tokach, S. Dritz, T. Houser, J. Nelssen, and R. Goodband. 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. *J. Anim. Sci.* 92:119–128. doi:10.2527/jas.2013-6679

Beaulieu, A. D., N. H. Williams, and J. F. Patience. 2009. Response to dietary digestible energy concentration in growing pigs fed cereal grain-based diets. *J. Anim. Sci.* 87:965–976. doi:10.2527/jas.2007-0834.

Boles, J. A., J. F. Patience, A. L. Schaefer, and J. L. Aalhus. 1994. Effect of oral loading of acid or base on the incidence of pale soft exudative pork (PSE) in stress-susceptible pigs. *Meat Sci.* 37:181–194. doi:10.1016/0309-1740(94)90079-5

Cheng, P., Y. Wang, J. Liang, Y. Wu, A. Wright, and X. Liao. 2018. Exploratory analysis of the microbiological potential for efficient utilization of fiber between lantang and duroc pigs. *Front Microbiol.* 9:1342. doi:10.3389/fmicb.2018.01342

Critser, D. J., P. S. Miller, and A. J. Lewis. 1995. The effects of dietary protein concentration on compensatory growth in barrows and gilts. *J. Anim. Sci.* 73:3376–3383. doi:10.2527/1995.73113376x.

Cromwell, G. L. 2005. Phosphorus and swine nutrition. In: Sims, J. T., and A. N. Sharpley, editors. *Phosphorus: agriculture and the environment*. Madison (WI): American Society of Agronomy; p 607–634.

Darriet, C., D. E. Axe, and T. D. Crenshaw. 2017. Acidogenic mineral additions increased Ca mobilization in prepartum sows. *J. Anim. Sci.* 95:212–225. doi:10.2527/jas.2016.0859

Dersjant-Li, Y., H. Schulze, J. Schrama, J. Verreth, and M. Verstegen. 2001. Feed intake, growth, digestibility of dry matter and nitrogen in young pigs as affected by dietary cation–anion difference and supplementation of xylanase. *J. Anim. Physiol. Anim. Nutr.* 85:101–109.

FASS. 2010. *Guide for care and use of agricultural animals in research and teaching*. 3rd ed. Champaign (IL): Federation of Animal Science Societies.

Hahn, W., R. Knight, C. G. Davis, J. Cessna, M. Haley, K. A. Ha, and G. Grossen. 2020. Livestock, dairy, and poultry monthly outlook: July 2020. Economic Research Service: United States Department of Agriculture LDP-M-313. <https://www.ers.usda.gov/publications/pub-details/?pubid=98847> [accessed September 30, 2020].

Haydon, K. D., J. W. West, and M. N. McCarter. 1990. Effect of dietary electrolyte balance on performance and blood parameters of growing-finishing swine fed in high ambient temperatures. *J. Anim. Sci.* 68:2400–2406. doi:10.2527/1990.6882400x.

Helm, E. T., J. W. Ross, J. F. Patience, S. M. Lonergan, E. Huff-Lonergan, L. L. Greiner, L. M. Reeve, C. W. Hastad, E. K. Arkfeld, and N. K. Gabler. 2021. Nutritional approaches to slow late finishing pig growth: implications on carcass composition and pork quality. *J. Anim. Sci.* 99:1–10. doi:10.1093/jas/skaa368

Kerr, B. J., F. K. McKeith, and R. A. Easter. 1995. Effect on performance and carcass characteristics of nursery to finisher pigs fed reduced crude protein, amino acid-supplemented diets. *J. Anim. Sci.* 73:433–440. doi:10.2527/1995.732433x.

Kerr, B. J., and G. C. Shurson. 2013. Strategies to improve fiber utilization in swine. *J. Anim. Sci. Biotechnol.* 4:11. doi:10.1186/2049-1891-4-11

Mauch, E. D., J. M. Young, N. V. L. Seroo, W. L. Hsu, J. F. Patience, B. J. Kerr, T. E. Weber, N. K. Gabler, and J. C. M. Dekkers. 2018. Effect of lower-energy, higher-fiber diets on pigs divergently selected for residual feed intake when fed higher-energy, lower-fiber diets. *J. Anim. Sci.* 96:1221–1236. doi:10.1093/jas/sky065

Menegat, M. B., S. S. Dritz, M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, and R. D. Goodband. 2020. A review of compensatory growth following lysine restriction in grow-finish pigs. *Transl. Anim. Sci.* 4:txaa014. doi:10.1093/tas/txaa014.

National Research Council. 2012. *Nutrient requirements of swine*, 11th rev ed., Washington (DC): The National Academies Press.

Norton, S., K. Betts, J. Jolliff, C. Pilcher, M. Ritter, J. Erickson, B. Ramer, C. Parsom, N. Gabler, and J. Patience. 2020. More details on so-called corn diet. [accessed February 1, 2021].

- <https://www.nationalhogfarmer.com/nutrition/more-details-so-called-corn-diet>
- Patience, J. F., R. E. Austic, and R. D. Boyd. 1987. Effect of dietary electrolyte balance on growth and acid-base status in swine. *J. Anim. Sci.* **64**:457–466. doi:10.2527/jas1987.642457x.
- Patience, J. F., and R. K. Chaplin. 1997. The relationship among dietary undetermined anion, acid-base balance, and nutrient metabolism in swine. *J. Anim. Sci.* **75**:2445–2452. doi:10.2527/1997.7592445x.
- Patience, J. F., and L. Greiner. 2020. Approaches to reducing feed intake and growth rate in market hogs during interruption of animal movement. [accessed January 28, 2020]. <http://www.ipic.iastate.edu/information/reducingFeedIntakeGrowthRate.pdf>
- Patience, J. F., and M. S. Wolynetz. 1990. Influence of dietary undetermined anion on acid-base status and performance in pigs. *J. Nutr.* **120**:579–587. doi:10.1093/jn/120.6.579.
- Pu, G., P. Li, T. Du, Q. Niu, L. Fan, H. Wang, H. Liu, K. Li, P. Niu, C. Wu, et al. 2020. Adding appropriate fiber in diet increases diversity and metabolic capacity of distal gut microbiota without altering fiber digestibility and growth rate of finishing pig. *Front. Microbiol.* **11**:533. doi:10.3389/fmicb.2020.00533.
- Rao, Z.-X., M. D. Tokach, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, and J. T. Gebhardt. 2021. Evaluation of nutritional strategies to slow growth rate then induce compensatory growth in 90-kg finishing pigs. *Transl. Anim. Sci.* doi:10.1093/tas/txab037
- Ruusunen, M., K. Partanen, R. Poso, and E. Puolanne. 2007. The effect of dietary protein supply on carcass composition, size of organs, muscle properties and meat quality of pigs. *Livest. Sci.* **107**:170–181. doi:10.1016/j.livsci.2006.09.021
- Sandra, B., F. Kati, and B. Martin. 2020. African swine fever—a review of current knowledge. *Virus Res.* **287**:198099. doi:10.1016/j.virusres.2020.198099
- Shi, J., L. Wang, and D. S. McVey. 2021. Of pigs and men: the best-laid plans for prevention and control of swine fevers. *Anim. Front.* **11**:6–13. doi:10.1093/af/vfaa052
- Soto, J. A., M. D. Tokach, S. S. Dritz, M. A. D. Gonçalves, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, M. B. Menegat, and F. Wu. 2019. Regression analysis to predict the impact of dietary neutral detergent fiber on carcass yield in swine. *Transl. Anim. Sci.* **3**:1270–1274. doi:10.1093/tas/txz113.
- Teta, D., A. Bevington, J. Brown, I. Pawluczyk, K. Harris, and J. Walls. 2003. Acidosis downregulates leptin production from cultured adipocytes through a glucose transport-dependent post-transcriptional mechanism. *J. Am. Soc. Nephrol.* **14**:2248–2254. doi:10.1097/01.asn.0000083903.18724.93.
- Tokach, M. D., B. D. Goodband, J. M. DeRouchey, J. C. Woodworth, and J. T. Gebhardt. 2021. Slowing pig growth during COVID-19, models for use in future market fluctuations. *Anim. Front.* **11**:23–27. doi:10.1093/af/vfaa047.
- Weber, E. K., K. J. Stalder, and J. F. Patience. 2015. Wean-to-finish feeder space availability effects on nursery and finishing pig performance and total tract digestibility in a commercial setting when feeding dried distillers grains with solubles. *J. Anim. Sci.* **93**:1905–1915. doi:10.2527/jas.2014-8136.
- Weber, T. E., S. L. Trabue, C. J. Ziemer, and B. J. Kerr. 2010. Evaluation of elevated dietary corn fiber from corn germ meal in growing female pigs. *J. Anim. Sci.* **88**:192–201. doi:10.2527/jas.2009-1896.
- Yen, J. T., W. G. Pond, and R. L. Prior. 1981. Calcium chloride as a regulator of feed-intake and weight-gain in pigs. *J. Anim. Sci.* **52**:778–782.