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Non Ruminant Nutrition

Strategies to manage barn feed supply to prolong and hold late finishing pigs during a supply chain disruption

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ABSTRACT

The U.S. pork production system is sensitive to supply chain disruptions, including those that can create challenges of feed delivery and feed management during the event of a foreign animal disease outbreak. Therefore, the objective was to evaluate feeding strategies during a prolonged feed availability shortage in group-housed finishing pigs and assess the impacts on pig performance. A total of 1,407 mixed-sex pigs (92 ± 11 kg BW) were randomly allocated to one of five treatments across 60 pens (*N* = 12 pens per treatment, 22 pigs per pen) and were blocked by initial body weight (BW) within the replicate, over a 21-d test period. Treatments were fed for 14 d (P1), and thereafter all pens returned to ad libitum access to a standard commercial diet for 7 d (P2). Treatments included: 1) Pens fed ad libitum (CON); 2) Pens fed at 1.45X ME maintenance requirement daily of CON diet (1.45X); 3) Pens fed 2X ME maintenance requirement daily of CON diet (2X); 4) Tightened feeders to the lowest setting, fed ad libitum of CON diet (CF); and 5) whole corn kernels, fed ad libitum (WC). P1 and P2 BW and feed disappearance were recorded to calculate ADG, ADFI, and G:F. Data were analyzed with pen as the experimental unit and least-squares means values reported by treatment. Compared to CON, pens fed 1.45X, 2X, CF, and WC treatments had significantly reduced P1 ADG (1.09 vs. 0.02, 0.34, 0.72, 0.41 kg/d, respectively), ADFI (3.21 vs. 1.42, 1.90, 2.49, 2.40 kg/d, respectively) and G:F ($P < 0.05$). During P2, ADG and G:F were increased ($P < 0.05$) compared to CON across all treatments. However, ADFI increased only in the 2X, CF, and WC diet from the CON ($P < 0.05$). Overall (days 0 to 21), all strategies attenuated BW, ADG, and ADFI ($P < 0.01$) compared to CON. However, G:F was only reduced ($P < 0.01$) in 1.45X and WC, but not 2X and CF ($P > 0.05$) compared to CON. In conclusion, all strategies explored could extend feed budgets. Even though these strategies were successful, increased BW variability was reported with more restrictive strategies. Further, adverse pig behaviors and welfare implications needs to be considered in adopting any restrictive feeding strategy.

LAY SUMMARY

As the swine industry is highly integrated, it is vulnerable to several supply chain disruptions. In the event of a feed supply chain disruption, the objective of this study was to investigate strategies to extend on-hand feeds to group-housed finishing pigs. Strategies investigated over the first 14-d period (P1) included: 1) ad libitum access to feed (CON), 2) feeding pigs to 1.45X their metabolizable energy for maintenance (ME_m) requirement daily (1X), 3) feeding pigs 2X ME_m daily (2X), 4) tightening feeders to tightest setting (CF), and 5) feeding unprocessed whole corn kernels (WC). Pig performance, carcass composition, and indicators of behavioral aggression were evaluated. In conclusion, all strategies explored could extend feed budgets. Even though these strategies were successful, increased BW variability was reported with more restrictive strategies. Further, adverse pig behaviors and welfare implications need to be considered in adopting any restrictive feeding strategy.

Key words: aggression, behavior, finishing pig, growth performance, maintenance energy, restrict feeding

INTRODUCTION

The swine industry is highly integrated and efficient due to optimum nutrition, genetics, timely pig movements, marketing, and a prolific meatpacking industry (Honeyman, 1996). Therefore, a goal for swine producers is to maximize pig health, wellbeing, and performance to optimize profitability within their system. Because the swine industry is highly integrated, any degree of disruption in the supply chain could jeopardize the efficiency and maximize throughput in any stage of production. Events such as feed mill shutdowns or malfunctions, labor shortages, cyber-attacks, packing plant shutdowns, or feed movement standstills as the result of foreign animal diseases, could all orchestrate pork supply chain disruptions. For instance, due to the COVID-19 pandemic in the spring of 2020, U.S. hog processing facilities were faced with labor shortages, leading to the inability to operate at full capacity (Hahn, 2020). This forced producers to alter pig production practices by reducing sow breeding (Wang et al., 2020), holding pig growth rates with diet adjustment (Helm et al. 2021a, 2021b), or mass culling and euthanasia (Meyer, 2020) of pigs that could not be marketed (Johnson et al., 2021). Further, supply chain vulnerability was highlighted in the summer of 2021, when one of the largest meat processors faced a cyber-attack and extortion threat that forced production to a halt (Creswell et al., 2021). Additionally, threats include the emergence of foreign animal diseases (FAD) such

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as African Swine Fever (ASF). Under the U. S. Department of Agriculture (USDA) ASF Response Plan, a National Movement Standstill policy will go into effect, stopping live swine movements between any facility within the impacted region for at least 72 h (USDA, 2020). Inability to access barns will prohibit feed deliveries and force producers to manage what feed is available to them.

In scenarios such as those listed above, implementing strategies to manage the on-farm feed supply and practical alternative diets to maintain the maintenance growth, wellbeing, and behavior is warranted. It is important to understand the adverse pig social consequences of feeding pigs below their optimal nutrient requirement or restrict feeding group-housed pigs. Therefore, the objective of this study was to evaluate feed and feeder management strategies to conserve growth, performance, and carcass composition of commercial group-housed finishing pigs. Furthermore, the second objective was to assess the effects of these strategies on behavioral aggression within a group-housed commercial setting.

MATERIALS AND METHODS

All animal procedures were approved by the Iowa State University Institutional Animal Care and Use Committee (IACUC protocol #21-042) and adhere to the ethical and humane use of animals for research. Live animal research was conducted at the United Animal Health Burton Russell Research site, Frankfort, IN, in April of 2021.

Animal, Housing, and Dietary Treatments

The barn consisted of tunnel ventilation and equipped with an automated feeding system (Big Dutchman, Vechta, Germany), where pens provided 0.73 m^2 of space per pig. Each pen had one hanging waterer and a three-hole feeder, with each hole measuring 40.6 cm wide by 30.5 cm deep. Sixty pens comprising of 22to 24 pigs per pen and a total of 1,407 mixed-sex finishing pigs (92 ± 11 kg BW; DNA 610 E × DNA 241 F1, DNA Genetics, Columbus, NE) and were randomly allocated to one of five treatments. Pens were blocked by initial body weight (BW) within replicate and assigned to one of five treatments (*N* = 12 pens per treatment). The five treatments included: 1) ad libitum access to feed (CON); 2) pens allotted 1.45X maintenance requirement per day (1.45X); 3) pens allotted 2X maintenance requirement per day (2X); 4) closed and tightened feeders to the lowest setting, fed ad libitum (CF); 5) whole corn kernels, fed ad libitum (WC).

Diets fed to treatments 1 to 4 were representative of a typical corn-soybean meal-based commercial finishing diet and formulated to meet nutrient requirements of this size pig (NRC, 2012). The WC treatment consisted of only non-ground whole yellow dent corn kernels. The energy and nutrient composition of these diets are shown in Table 1. The CON, CF, and WC treatments were offered ad libitum; however, CF had the feeder opening reduced to the lowest setting that resulted in approximately 5% to 8% pan coverage. For 1.45X and 2X treatments, pigs were fed daily based on the pen's average maintenance energy requirements based on the average BW of the pen. Maintenance requirements (daily metabolizable energy of maintenance, [ME_m, kcal/d]) were calculated based on the National Research Council (NRC, 2012):

$$ME_m\ (kcal/d) = 197\ kcal/kg\ BW^{0.60}$$

Table 1. Diet formulation and calculated nutrient composition, as fed basis

Ingredient, %	Control	Whole corn[7]
Corn	72.40	100
DDGS[1]	20.00	-
Soybean meal	4.37	-
Limestone	1.01	-
Choice white grease	1.00	-
Salt	0.57	-
Lysine-HCl	0.35	-
Threonine	0.07	-
Tryptophan	0.02	-
Vitamin/trace mineral premix[2]	0.20	-
Phytase[3]	0.01	-
Calculated composition		
Dry Matter, %	84.95	88.31
Metabolizable Energy, Mcal/kg	3.15	3.40
Crude Protein, %	12.47	8.24
Crude Fat, %	4.81	3.48
Crude Fiber, %	1.56	1.98
ADF[4], %	3.57	2.88
NDF[5], %	9.80	9.11
Total calcium, %	0.45	0.02
Total phosphorus, %	0.36	0.26
Available phosphorus, %	0.22	-
SID Lysine[6], %	0.61	0.19
SID Lys:ME[6], g/Mcal	1.94	0.05
SID AA:Lys, %		
Met+Cys:Lys	0.60	1.59
Thr:Lys	0.65	1.13
Trp:Lys	0.18	0.25
Val:Lys	0.72	1.64

[1]DDGS = corn distiller's dried grains with soluble
[2]Vitamin and trace mineral premix provided per kilogram of diet: 3,002 IU vitamin A, 1,086 IU vitamin D, 25 IU vitamin E, 0.51 ppm vitamin K, 34.6 mg niacin, 19 mg pantothenic acid, 4.4 mg riboflavin, 23 µg vitamin B12, 20.4 µg folic acid, 3 µg chromium, 110 ppm Zn, 98 ppm Fe, 40 ppm Mn, 12 ppm Cu, 50 µg Co.
[3]Phytase enzyme 2,500 providing 0.125 available Phosphorus.
[4]ADF = acid detergent fiber.
[5]NDF = neutral detergent fiber.
[6]SID = standardized ileal digestibility.
[7]Whole corn composition derived from NRC: Yellow Dent corn (NRC, 2012).

Based on the average BW of each pen and the diet ME of 3,150 kcal/kg, the average pigs' ME_m was calculated and then multiplied by either 1.45X or 2X and the number of pigs per pen. This amount of feed was offered once per day to the pen. Feed was delivered to each pen at approximately 0900 hours each morning. The treatment diets were offered in period 1 (P1) from day 0 to 14 and only pigs in pens fed the CON and CF had ad libitum access to feed. For period 2 (P2), on day 15 through the end of the study at day 21, and until market, all pens were fed the control treatment consisting of the corn-soybean meal mashed diet, feed ad libitum. At all times pigs had free access to water.

Animal Performance and Carcass Measurements

Individual pig BWs were recorded on days 0, 14, and 21 to be used to calculate pen average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (gain:feed, G:F). Pigs were marketed at two timepoints ranging from 12 to 18 d apart. The first timepoint marketed the heaviest half of the pigs per pen starting a week after the completion of the trial, while the second cut emptied the pen 12 to 18 d later. Treatments within a replicate were all sold on the same day. Pigs were individually tattooed according to pen number before loading and shipped to a commercial harvest facility (Tyson Foods, Logansport, IN) to collect carcass composition data (backfat depth, loin depth, percent lean, and percent yield). Carcass ADG (CADG) was calculated by subtracting the estimated starting carcass weight (starting pen average weight × 75% dressing) from the pen average carcass weight, then dividing by total pig days by headcount sold. (Avg. Carcass wt. − (starting avg wt. × 0.75))/(total pig days/head shipped). Carcass FCR (CFCR) was calculated by dividing CADG by the cumulative live ADFI, calculated from the cumulative data collected in the last measured period.

Behavior Assessment

Pigs were observed by the same individual on days 0 through 14, and again on day 21 for behavior assessments based on Pork Quality Assurance (PQA, 2018) rubrics and Swine Care Handbooks by the Pork Checkoff (NPB, 2018). Visual assessments of each pig were conducted daily and completed before feeding. Parameters were recorded for the number of pigs within each pen with ear bites, tail bites, sores/side bites, and scratches. Ear bites were classified as any visible lesions or open flesh on the ear. Tail bites were evaluated as any sign of biting on the tail, regardless of the degree of severity. Sores and side bites were classified as circular open wounds on any part of the body: neck, side, back, flank, and hind legs. Scratches were identified as linear wounds, either produced from teeth marks or hoofs, irrespective of the source. Scratches ranged from red marking > 2 inches in length produced from teeth to open wound scratches. Total abrasions indicate a sum of ear bites, tail bites, side bites and sores, and scratches. All markings were summed over the number of pigs per pen to get a percentage of total wounds per pen and reported on days 0, 3, 7, 10, 14, and 21 to determine the change over time.

Statistical Analysis

Growth performance and carcass composition data were analyzed using the mixed model procedure of SAS (version 9.4; SAS Inst. Inc., Cary, NC). With pen used as the experimental unit and pig as the observational unit. Growth performance (P1, P2, and overall) and carcass composition parameters were analyzed for the fixed effects of dietary treatment using the following model:

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

Where Y_{ijk} = the parameter measured on pen k, μ = the overall effect mean, Diet_i = the fixed effect of dietary treatment, Rep_j = random effect of repetition within barn, and e_{ijk} = the overall error. Least squares (LS) means were determined using LS means statement with the pdiff option using Tukey–Kremer's adjustment to account for multiple comparisons. Growth performance and carcass composition data are presented as LS means with a pooled standard error of the mean. Differences were considered significant when $P < 0.05$ and a tendency when $0.05 \le P \le 0.10$.

All visual assessment of behavior data were analyzed using the PROC MIXED procedure of SAS (version 9.4; SAS Inst. Inc., Cary, NC) using a similar model as growth performance. Data were analyzed with repeated measures at days 0, 3, 7, 10, 14, and 21 for the fixed effect of treatment, day, and the interaction. Pen was considered as the experimental unit and pig as the observational unit of analysis. Tukey–Kremer's adjustments were used for multiple comparisons. LS means are reported as the average percentage of pigs per pen with the localized lesions at specific time points. Treatment, day, and interaction differences were considered significant when $P < 0.05$ and a tendency when $0.05 \le P \le 0.10$.

RESULTS

Growth Performance

All growth performance data for P1, P2, and overall are reported in Table 2. Day 0 starting BW was the same across all treatments ($P = 0.75$). During the 14-d diet intervention period (P1), BW, ADG, ADFI, and G:F were all reduced in the pigs in pens that were fed 1.45X and 2X, CF, and WC compared to pens that were fed CON ($P < 0.01$). Feeding pigs 1.45X resulted in a static BW change and minimal ADG to the CON pigs ($P < 0.01$). Furthermore, 2X and WC treatments resulted in ~10 kg BW lighter pigs on day 14 and a 62% and 69% reduction in ADG, respectively, from the CON pigs ($P < 0.01$). The CF treatment caused a 34% reduction in ADG compared to the CON treatment in P1 ($P < 0.01$). The ADFI of all treatments in P1 were significantly reduced compared to the CON, with 1.45X and 2X resulting in a 55% and 40% reduction in ADFI ($P < 0.01$). Both CF and WC fed pigs caused ADFI to drop by ~24% from the CON ($P < 0.01$). As expected, feed efficiency (G:F) was significantly reduced by all treatments from the control in P1 ($P < 0.01$; Table 2).

During days 15 through 21 (P2), all pens returned to ad libitum access to the corn-soybean meal-based mashed diet. Compared to the CON group, P2 ADG was significantly increased by 186%, 167%, 140%, and 131% for 1.45X, 2X, CF, and WC treatment groups, respectively ($P < 0.01$; Table 2). In P2, 2X, CF, and CON treatments had a 5% to 9% increase in ADFI compared to the CON ($P < 0.01$), with the 1.45X treatment being intermediate. Interestingly, 1.45X, 2X, CF, and WC treatments all had enhanced feed efficiency (G:F) from the CON when all on the same ad libitum diets ($P < 0.01$).

Overall (days 0 to 21), pigs fed 1.45X, 2X, CF, and WC had a 3 to 10 kg lower BW compared to the CON pigs ($P < 0.01$; Table 2). During the duration of the study period, ADG and ADFI were reduced in pens fed 1.45X and 2X maintenance, CF, and WC ($P < 0.01$), compared to pigs on the CON treatment ($P < 0.01$). Compared to CON, day 0 to 21 G:F was reduced in treatments fed 1.45X and WC ($P < 0.01$). However, G:F was not different from the CON pigs in pens fed 2X and CF treatments ($P > 0.05$), resulting from a higher feed consumption per day in P2. The standard deviation between each pen at day 0 was not different across treatments; however, at day 14, 2X and WC had an increased standard deviation in BW compared to CON ($P < 0.01$; Table 2). By day 21, there were no differences in standard deviation from CON. There was no difference between treatments in percentage change in standard deviation in days 0 to 14 or days 0 to 21 in the pens fed CF and WC; however, the 2X and

Table 2. Effects of feed restricting strategies on growth performance and BW variation of late finishing pigs

Item	CON	2X	1.45X	CF	WC	SEM	*P*-value
BW, kg							
Day 0	92.1	92.4	92.4	92.3	92.3	0.65	0.752
Day 14	107.5^{a}	97.3^{c}	92.6^{d}	102.4^{b}	98.1^{c}	0.74	<0.001
Day 21	113.3^{a}	107.8^{c}	103.6^{d}	110.8^{b}	105.7^{c}	0.69	<0.001
Period 1, days 0-14[1]							
ADG, kg	1.09^{a}	0.34^{c}	0.02^{d}	0.72^{b}	0.41^{c}	0.036	<0.001
ADFI, kg	3.21^{a}	1.90^{c}	1.42^{d}	2.49^{b}	2.40^{b}	0.042	<0.001
G:F	0.34^{a}	0.18^{c}	0.01^{d}	0.29^{b}	0.17^{c}	0.013	<0.001
Period 2, days 15-21[2]							
ADG, kg	0.84^{c}	1.40^{a}	1.56^{a}	1.18^{b}	1.10^{b}	0.060	<0.001
ADFI, kg	2.94^{c}	3.15^{a,b}	3.02^{b,c}	3.20^{a}	3.10^{a,b}	0.043	<0.001
G:F	0.28^{c}	0.45^{a}	0.52^{a}	0.37^{b}	0.36^{b}	0.020	<0.001
Overall, days 0-21							
ADG, kg	1.01^{a}	0.69^{c}	0.53^{d}	0.87^{b}	0.64^{c}	0.022	<0.001
ADFI, kg	3.12^{a}	2.32^{c}	1.95^{d}	2.73^{b}	2.63^{b}	0.035	<0.001
G:F	0.32^{a}	0.30^{a}	0.27^{b}	0.32^{a}	0.24^{b}	0.009	<0.001
BW Standard deviation, kg							
Day 0	11.54	11.79	11.27	10.95	10.78	0.471	0.542
Day 14	12.59^{b,c}	14.91^{a}	13.76^{a,b}	12.03^{b,c}	11.48^{c}	0.554	<0.001
Day 21	13.08^{a,b}	15.16^{a}	14.06^{a,b}	12.72^{b}	12.69^{b}	0.556	0.006
% change BW Standard deviation							
Day 0 to 14	9.20^{b}	26.63^{a}	22.61^{a}	9.66^{b}	6.90^{b}	2.356	<0.001
Day 0 to 21	13.87^{c}	28.92^{a}	25.23^{a,b}	16.06^{b,c}	18.47^{b,c}	2.716	<0.001

[1]Fed restricted diets days 0 to 14 on test diets.
[2]Fed ad libitum days 15 to 21 the Control diet.
[a,b,c,d]Means within a row with differing superscripts differ significantly at $P < 0.05$.

1.45X had a greater percent change in spread of BW at both days 14 and 21 (both $P < 0.01$) from CON.

Carcass Composition

At the end of the study, carcass composition data were collected at a commercial harvest facility in two market cuts (Cut 1 and Cut 2; Table 3). Irrespective of cut, the 1.45X, 2X, CF, and WC treatments had reduced average shipped BW compared to the CON treatment in the first cut, ranging from 2.8 to 7.4 kg reduction in BW ($P < 0.01$). In the second cut, BW of shipped pigs was reduced from CON pigs by 9.1, 6.9, and 6.6 kg, in the 1.45X, 2X, and WC treatment groups, respectively ($P < 0.01$). However, the CF treatment shipping BW in cut 2 was similar to the CON ($P > 0.05$). Reduction in live weight at shipping translated similarly to a difference in carcass weight between treatments. Compared to the CON, the first cut's average carcass weights were reduced in pens fed 1.45X and WC by 6% and 4%, respectively ($P < 0.01$). However, carcass weights tended to be reduced by ~3% in pigs from the 2X pens compared to the CON carcasses ($P = 0.056$). No carcass weight differences in either cut were reported between CON and CF treatment pens ($P > 0.05$). Interestingly, backfat depth was similar across most treatments in cuts 1 and 2 ($P > 0.05$), except the 1.45X treatment which reduced backfat by 8% compared to the CON in the second cut ($P < 0.05$). As expected, the WC diet reduced loin depth by ~6% and 5% in cuts 1 and 2, respectively ($P < 0.01$) and feeding 1.45X by 5% in cut 2 ($P < 0.01$). No differences were reported in loin depth for treatment 2X and CF in either cut 1 or 2 ($P > 0.05$). Although carcass yields were similar amongst all treatments, carcass percent lean was only reduced in the WC treatment from the CON by 0.7% and 0.6% in cuts 1 and 2, respectively ($P < 0.05$). No differences were reported in yield percentages between 1.45X, 2X, CF, and WC from the control treatment ($P > 0.05$; Table 3).

Behavioral Assessment

To evaluate the effect of dietary intervention treatment on pig behavior, aggression indices (i.e., ear bites, side bites and sores, tail bites, and scratches) were assessed and recorded. A daily accruing count of each category within pen was then reported as a percentage of the total head per pen. In total abrasions (the sum of ear bites, side bites and sores, tail bites, and scratches), there was a treatment by day interaction (Table 4); as time elapsed over P1, pigs on the 1.45X, 2X, CF, and WC treatments had an increase ($P < 0.01$) in the percentage of pigs per pen with markers indicating aggression compared to CON pens. The driving parameter behind the increase in total markings was the percentage of scratches ($P < 0.01$). Compared to CON, all four treatments resulted in a higher percentage of pigs with scratches greater than 2 inches ($P < 0.01$). Further, an increased percentage of pigs with tail bites in P1 was reported in the 1.45X, 2X, CF, and WC treatments, relative to the CON ($P < 0.01$). However, no differences amongst treatments ($P > 0.05$) were reported in sores, side bites, and ear biting.

Table 3. Carcass composition of pigs placed on feed restricting strategies

Item	CON	2X	1.45X	CF	WC	SEM	*P*-value
Shipped weight, kg							
Cut 1	131.3^{a}	127.8^{b}	123.9^{c}	128.5^{b}	124.1^{c}	0.736	<0.001
Cut 2	128.6^{a}	121.7^{b}	119.5^{b}	126.6^{a}	122.0^{b}	1.184	<0.001
Overall	130.0^{a}	124.7^{c}	121.5^{d}	127.5^{b}	123.2^{c,d}	0.656	<0.001
Carcass avg wt, kg							
Cut 1	96.4^{a}	93.3^{a,b,c}	91.0^{c}	94.8^{a,b}	92.5^{b,c}	1.000	0.001
Cut 2	94.8^{a}	89.2^{c}	87.7^{c}	93.2^{a,b}	89.4^{b,c}	1.201	<0.001
Overall	95.3^{a}	91.4^{b}	88.3^{c}	93.9^{a}	90.6^{b,c}	0.829	<0.001
Fat depth, cm							
Cut 1	1.30	1.22	1.20	1.27	1.30	0.05	0.126
Cut 2	1.17^{a}	1.08^{a,b}	1.05^{b}	1.15^{a,b}	1.14^{a,b}	0.035	0.018
Overall	1.21^{a}	1.16^{a,b}	1.11^{b}	1.20^{a}	1.21^{a}	0.031	0.007
Loin depth, cm							
Cut 1	6.31^{a}	6.16^{ab}	6.09^{a,b}	6.18^{a,b}	5.95^{b}	0.072	0.011
Cut 2	7.28^{a}	7.10^{a,b,c}	6.91^{c}	7.19^{a,b}	6.89^{b,c}	0.092	0.001
Overall	7.28^{a}	7.12^{a,b}	6.93^{b,c}	7.18^{a}	6.89^{c}	0.058	<0.001
Lean, %							
Cut 1	57.2^{a}	57.2^{a}	57.0^{a,b}	57.1^{a,b}	56.5^{b}	0.169	0.029
Cut 2	57.6^{a}	57.5^{a,b}	57.2^{a,b}	57.5^{a,b}	57.0^{b}	0.173	0.043
Overall	57.8^{a}	57.4^{a}	57.2^{a,b}	57.4^{a}	56.9^{b}	0.119	0.001
Yield, %							
Cut 1	73.4	72.7	73.3	74.0	74.3	0.658	0.294
Cut 2	74.1	73.2	74.3	73.6	73.5	0.611	0.535
Overall	74.0	72.7	73.6	73.8	73.9	0.502	0.215
Overall CADG, kg	0.74^{a}	0.63^{b}	0.54^{c}	0.70^{a}	0.61^{b}	0.019	<0.001
Overall CFCR, kg	1.96^{b}	2.01^{a,b}	2.20^{a}	1.94^{b}	2.20^{a}	0.061	0.001

^{a,b,c}Means within a row with differing superscripts differ significantly at $P < 0.05$.
CADG: Carcass ADG.
CFCR: Carcass Feed conversion ratio.

DISCUSSION

The pig supply chain is highly integrated and efficient in breeding, management, and marketing. As a result, supply chain disruptions can greatly impact pig producers and pork consumers. In recent years, this supply chain has faced the threat of FAD (Blome et al., 2020), cyber-attacks (Creswell et al., 2021), and global pandemics such as COVID-19 (Johnson et al., 2021), all of which have imposed disruptions to the efficiency of pork production. In the case of a potential FAD outbreak in the U.S., a National Movement Standstill policy (USDA, 2020) will likely go into effect prohibiting commercial truck movement between pig sites within the impacted region for at least 72 h. This inability of commercial truck access to barns may significantly impact feed deliveries and pig marketing, forcing producers to manage what feed is available on-hand and slow pig growth.

To protect the plasticity of the pork supply chain, we explored strategies producers may implement on-farm if feed supply and delivery become limited. In such a scenario, management strategies will need to be adopted to stretch feed budgets or modify ingredients to sustain pig wellbeing, health, and productivity. Three strategies were explored to manage finishing pigs to extend feed budgets or feed locally stored whole grain if feed truck movements were restricted. One practical strategy evaluated to stretch on-hand feed budgets was the approach of restrict or limit feeding group-housed pigs based on 1.45X and 2X feeding above the average maintenance requirement of the pen. When feed is offered to the pig, their voluntary feed intake provides the nutrients needed from the diet to promote optimal growth at that stage (Nyachoti et al., 2004). As pigs eat to their energy needs (Jasper et al., 2020), and based on the energy content of the diet, ad libitum feed intake in growing pigs is typically 2.8 to 3.2X the maintenance energy requirement (NRC, 2012). When pigs consume feed below this level of energy intake, amino acids, vitamins, and minerals are consumed at levels below what is desired for maximal lean tissue accretion. This has been clearly demonstrated in 35 kg BW (Boddicker et al., 2011b) and 75 kg BW (Boddicker et al., 2011a) individually penned growing pigs. Boddicker et al. (2011a, 2011b) reported a growth reduction of 20% to 30% in feeding 75% of ad libitum (~2.2X maintenance) and a 47% to 48% when feeding 55% of ad libitum (~1.65X maintenance). Further, by design, feeding pigs at maintenance requirements resulted in static BW or ADG over the study duration of the feeding period (Boddicker et al. 2011a; 2011b). In agreement with these findings, we report that feeding group penned pigs for 14 d at 1.45X or 2X maintenance, ADG was more severely reduced, resulting in a 98% and 69% reduction from the ad libitum control, respectively.

Table 4. Behavioral assessment of restrict fed late finishing pigs

Item	CON	2X	1.45X	CF	WC	SEM	*P*-value		
							Trt	Day	Trt*Day
Ear bites, %									
day 0[1]	0.0	0.4	0.0	0.0	1.1	0.72	0.108	<0.001	0.493
day 3[1]	0.0	0.7	0.0	0.0	0.0				
day 7[1]	0.0	0.7	0.0	0.7	2.1				
day 10[1]	0.4	1.1	1.4	2.5	2.1				
day 14[1]	1.1	2.5	3.2	2.5	4.6				
day 21[2]	0.0	0.0	0.0	0.0	1.1				
Sores/ Side bites, %									
day 0[1]	0.4	0.4	0.0	0.0	0.0	1.23	0.346	<0.001	0.685
day 3[1]	1.7	1.4	2.1	0.7	1.7				
day 7[1]	1.4	4.4	3.2	1.8	1.4				
day 10[1]	2.1	3.6	1.8	2.8	3.9				
day 14[1]	1.4	4.0	1.4	2.5	3.6				
day 21[2]	0.4	1.5	0.4	1.0	0.0				
Tail bites, %									
day 0[1]	0.0[c]	0.0[c]	0.0[c]	0.0[c]	0.0[c]	0.85	<0.001	<0.001	<0.001
day 3[1]	0.0[c]	0.4[b,c]	0.7[b,c]	0.4[b,c]	0.4[b,c]				
day 7[1]	0.4[b,c]	1.8[b,c]	2.5[b,c]	0.4[b,c]	1.0[b,c]				
day 10[1]	0.7[b,c]	2.2[b,c]	1.4[b,c]	0.4[c]	1.1[b,c]				
day 14[1]	0.7[b,c]	1.4[b,c]	6.8[a]	3.5[b]	1.4[b,c]				
day 21[2]	0.0[c]	0.0[c]	0.4[b,c]	0.0[c]	0.0[c]				
Side scratches, %									
day 0[1]	0.0[g]	0.0[g]	0.0[g]	0.0[g]	0.0[g]	2.10	<0.001	<0.001	<0.001
day 3[1]	1.1[f,g]	8.3[e,f,g]	12.1[d,e,f]	4.9[e,f,g]	4.6[e,f,g]				
day 7[1]	5.3[e,f,g]	22.2[a,b,c,d]	25.3[a,b]	12.7[d,e]	10.6[e,f,g]				
day 10[1]	4.7[e,f,g]	22.3[a,b.c.d]	25.3[a,b]	12.7[d,e]	14.4[b,c,d,e]				
day 14[1]	4.4[e,f,g]	27.9[a]	23.9[a,b,c]	9.5[e,f,g]	13.0[c,d,e]				
day 21[2]	0.0[g]	0.0[g]	0.4[g]	0.4[g]	0.4[g]				
Total abrasions, %									
day 0[1]	0.7[h,i]	1.1[g,h,i]	0.0[i]	0.0[i]	1.1[g,h,i]	2.84	<0.001	<0.001	<0.001
day 3[1]	2.8[g,h,i]	11.2[d,e,f,g,h,i]	16.0[c,d,e,f,g]	5.9[f,g,h,i]	6.7[f,g,h,i]				
day 7[1]	7.8[e,f,g,h,i]	29.8[a,b,c]	33.5[a,b]	15.5[c,d,e,f,g,h]	15.5[c,d,e,f,g,h]				
day 10[1]	9.0[e,f,g,h,i]	33.1[a,b]	33.1[a,b]	19.4[b,c,d,e.f]	21.8[b,c,d,e]				
day 14[1]	9.0[e,f,g,h,i]	42.4[a]	40.7[a]	19.3[b,c,d,e,f]	24.4[b,c,d]				
day 21[2]	0.4[i]	1.9[g,h,i]	1.1[g,h,i]	1.8[g,h,i]	1.4[g,h,i]				

[a,b,c,d,e,f,g,h,i]Means within parameter with differing superscripts indicate an interaction, significant differences at $P < 0.05$.
[1]days 0 to 14, P1: Fed according to treatment restrictions.
[2]days 15 to 21, P2: All pens fed ad libitum.

Further, G:F was also reduced in both the 1.45X and 2X, similarly to that reported by Boddicker et al. (2011a, 2011b) in pigs fed at 2.2X and 1.65X. Although growth performance was significantly reduced, the 2X and 1.45X maintenance feeding strategies on a group pen basis would stretch feed budgets 2- to 3-fold.

The second strategy examined the practical approach of tightening and managing feeder adjustments as a short-term solution to extend feed. In the CF treatment, feeders could not be completely shut but tightened to the lowest setting, which provided approximately 5% to 8% trough coverage. As a result, pigs exerted effort to obtain more feed after a few days, and this strategy only resulted in a decrease in ADFI of about 22% from the CON. Although tightening feeders completely for the intent of restricting intake has not been studied, multiple studies have reported similar reductions in ADFI (Duttlinger et al., 2008; Myers et al., 2012). These studies reported that ADFI reduced by 4% to 8% as trough pan coverage drops below 30%, which are in alignment with the results of this study. For reference, CON ad libitum feeders in this study were set to provide roughly 40% to 50% trough coverage. Duttlinger et al. (2008) reported a pan coverage of a little more than 50% provides optimal ADG and ADFI on finishing performance, while anything less than that is restricting maximum performance potentials.

In the event of a FAD, and the subsequent prospect of a 72-h National Movement Standstill policy that could include feed movements (USDA, 2020), producers may need to utilize local sources of whole-unprocessed grain to achieve satiation for pigs in barns to offset potential adverse pig behaviors and welfare concerns. Although feeding unprocessed corn has not been widely studied, this strategy reduces essential AA, energy, and nutrients below requirements for optimal growth (Kerr et al., 1995). As expected, 100% whole Corn diets reduced ADG and, to a lesser extent, ADFI. These results are similar to recent reports in which feeding ad libitum meal diets containing 97% ground corn and no synthetic AA resulted in a 47% reduction in ADG (Helm et al., 2021b). However, Helm et al. (2021b) observed no differences in ADFI over a 2 to 6-wk period when feeding these high ground corn (97% of diet composition) diets, compared to a nutritionally adequate control diet, but feed efficiency was reduced. This contrasts with the 25% reduction in ADFI in the WC pens reported herein. This discrepancy may result from the grinding process increasing nutrient and energy availability of corn (Rojas and Stein, 2015) and the diets utilized by Helm et al. (2021b) still containing adequate vitamins and minerals. Mineral deficiency is known to reduce voluntary feed intake. Further, the increased bulk density of corn kernels over mash diets may slow passage time and induce increased satiation (Anguita et al., 2007).

No matter the strategy employed, reducing voluntary feed intake in pigs, or feeding unbalanced AA and nutrient-deficient diets impact protein synthesis and lean tissue accretion. In agreeance with published literature, limiting essential amino acids and energy reduces protein deposition and pig growth (Easter and Baker, 1980; Prince et al., 1983; Adeola and Young, 1989; Ruusunen et al., 2007). Although only implemented for 14 d followed by 7 d of normal feeding in late finishing, carcass yields, loin depth, and backfat were slightly decreased by WC and maintenance feeding. The data marginally agrees with Quiniou et al. (2012) who reported no statistical differences in percentage lean and loin depth but a reduction in backfat when feeding 78% and 86% of ad libitum to market pigs. Further, increases in backfat and decrease in percent lean during a time of essential nutrient deficiencies have been widely reported in growing pigs (Easter and Baker, 1980; Kerr et al., 1995). Unsurprisingly, feed restriction in the form of maintenance feeding reduces backfat (Boddicker et al., 2011a).

In confinement settings, competition for food increases skin injuries and aggression in pigs (Botermans and Svendsen, 2000). Adverse social behaviors, such as tail biting, may also be frequented in late finishing when stocking density is high (Jensen, 1971; Randolph et al., 1981). In terms of feed allowance, Vargas et al. (1987) and Quiniou et al. (2012) have reported that more aggressive interactions were displayed in restricted-fed pigs compared to pigs that had free access to feed. Further, aggression and lesions are influenced by meal frequency in pigs. Hessel et al. (2006) reported higher lesion scores in pigs fed smaller meals more frequently due to increased activity and competition around the feeder. De Leeuw et al. (2008) and Tokach et al. (2021) have also reported that restricting feed access increases aggression to grow-finish pigs. Thus, providing insufficient nutrients or restricting feed intake may come with increased welfare concerns (De Leeuw et al., 2008). It has also been suggested that an amino acid deficiency may lead to increased aggression (Meer et al., 2017). However, this study observed marginal increases in biting and aggression indicators with pigs fed an amino acid-deficient diet. These data do not agree with Helm et al. (2021b), in which commercial late finishing pigs fed with 97% ground corn had no indicators for increased aggression. In the case of a FAD outbreak, feed availability and the welfare concerns associated with feed outages may become problematic. Our data suggests that over the 14-d intervention period, maintenance feed and restrict feeding increased indices of behavioral aggression by 10% to 30% compared to CON pigs. When determining a strategy, producers must be aware of the welfare concerns and increased aggression indicators when implementing strategies to stretch feed budgets.

CONCLUSIONS

Although rare, scenarios may arise where the swine industry will need to adapt to accommodate a short-term disruption in the supply chain, particularly with feed supply. Herein, we investigated strategies to limit feed intake to extend feed budgets of grow-finish pigs in scenarios where feed supply can be disrupted and their effects on social interaction amongst the cohort in the form of indicating markers of aggression. The explored strategies included feeding to the energy maintenance requirement, manipulating feeder settings to limit intake, and providing unprocessed whole corn kernels. We hypothesized that growth performance, especially ADFI, and aggressive behavior would be compromised with the implemented management strategies, but the severity of each strategy was unknown. Our data supported this hypothesis in that all strategies explored could extend feed budgets. Even though these strategies were successful, the increase in variability of BW within each pen may be due to the social structure within pens. Adverse pig behaviors and welfare implications needs to be considered in adopting any strategy. Furthermore, these strategies had a marginal impact on carcass measures. The results from this study provide producers with strategies to implement when feed budgets are needed to be extended.

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Conflict of interest statement

DG is employed by United Animal Health. All other authors have no conflicts of interest.

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