Effects of floor space and removal of corn distillers dried grains with solubles on heavy weight pig performance

by

Anne Bonner Lerner

B.S., Kansas State University, 2015
M.S., Kansas State University, 2016

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

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2019

Abstract

This dissertation is comprised of 5 chapters consisting of a study evaluating space allowance and marketing strategies for pigs raised to 160 kg, three experiments evaluating the impact of removing corn distillers dried grains with solubles (DDGS) from finishing pig diets, four studies evaluating the use of medium chain fatty acids (MCFA) as a mitigation strategy for porcine epidemic diarrhea virus (PEDV), and development of a swine-specific undergraduate research program. In Chapter 1, four treatments were evaluated with decreasing space allowance from 1.17 to 0.71 m2/pig with only one final marketing event, plus two treatments with restricted space allowance and four or three marketing events. Increasing space allowance via increased initial pen inventory increased average daily gain (ADG), decreased average daily feed intake (ADFI), and reduced feed efficiency (G:F). Marketing pigs 3 or 4 times improved G:F compared with to the similar treatment with only one marketing event but resulted in similar weight marketed per pen. In chapter 2, pigs were switched from diets containing corn DDGS to corn- and soybean-meal based diets (CSBM) starting at 76 d prior to market. As time consuming CSBM increased, ADG and final BW increased and G:F improved. Average daily feed intake decreased with increasing time after dietary switch to CSBM. Hot carcass weight increased and iodine value decreased with increasing time after DDGS removal from diets. Chapter 3 also evaluated the removal of corn DDGS from finishing pig diets but utilized two seasonal marketing strategies. Regardless of marketing strategy, switching pigs from DDGS to CSBM resulted in increased carcass yield and decreased iodine value, yet live growth performance was marginally impacted. In chapter 4, four experiments were conducted to evaluate the efficacy of applying MCFA to swine feed on detection and infectivity of PEDV. Applying chemical mitigants both prior to and post-PEDV inoculation was effective at reducing PEDV detection via

quantitative real time reverse transcriptase polymerase chain reaction (qRT-PCR). When tested individually and in combination and applied before viral inoculation, caproic and caprylic acid appeared to provide the greatest reduction of detectable genetic material. The addition of a 1:1:1 blend of C6:C8:C10 at 0.5% and 0.3% C8 prevented infection in in vivo bioassay. Lastly, chapter 5 presents a model to develop a species-specific undergraduate research program in the context of a swine nutrition program that is currently in use at Kansas State University. This program utilizes both graduate students and faculty to provide mentorship and has several project types that vary in level of student involvement. The program is designed to provide a comprehensive research experience, with an emphasis on including the student in pre- and post-trial activities beyond data collection. A majority of students that complete the undergraduate research program enter graduate or veterinary degree programs upon completion of their undergraduate work and cite undergraduate research as a critical step in their career selection process and professional development.

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Approved by:

Co-Major Professor
Dr. Mike Tokach

Approved by:

Co-Major Professor
Dr. Jason Woodworth

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Dedication

This dissertation is dedicated to my mom and dad, Keith and Bit, and my husband, Bracey.

Preface

This dissertation is original work completed by the author, A.B. Lerner. Chapters 1 through 4 were formatted for publication according to the required standards of the Journal of Animal Science and Translational Animal Science. Chapter 5 is formatted for publication in Natural Sciences Education.

Chapter 1 - Effect of space allowance and marketing strategy on growth performance of pigs raised to heavy market weights

ABSTRACT

A total of 976 pigs (PIC 327 × Camborough; PIC, Hendersonville, TN; initially 22.0 ± 1.53 kg body weight [**BW**]) were used in a 160-d growth study to evaluate the effects of increasing space allowance and varying removal strategies on growth performance of pigs raised to heavy market weights (approximately 165 kg). Pens of pigs were blocked by location within the barn and allotted to 1 of 6 treatments. Pen served as the experimental unit, and there were 8 replicate pens per treatment. The first four treatments consisted of increased initial stocking density and did not utilize topping strategies: 1) 14 pigs/pen (1.17 m^2/pig), 2) 17 pigs/pen (0.97 m^2/pig), 3) 20 pigs/pen (0.82 m^2/pig), and 4) 23 pigs/pen (0.71 m^2/pig). The fifth treatment began with 25 pigs/pen (0.66 m^2/pig) and had 4 marketing events with the heaviest 3 pigs/pen removed on d 93, and additional pigs removed to a common inventory of 20 pigs/pen on d 122 and 17 pigs/pen on d 147 with final marketing on d 160. The final treatment began the experiment with 23 pigs/pen (0.71 m^2/pig) with 3 marketing events to achieve a common inventory of 20 pigs/pen on d 108 and 17 pigs/pen on d 147. Pens of pigs were weighed and feed disappearance measured on d 0, 93, 108, 122, 135, 147, and 160. As space allowance decreased from 1.17 to 0.71 m^2/pig via increased initial pen inventory (treatments 1 to 4), overall average daily gain (**ADG**) and (**ADFI**) decreased (linear, $P < 0.001$), while feed efficiency (**G:F)** did not differ ($P > 0.05$). The treatments with multiple marketing events were compared with each other and with the treatment that began with 0.71 m^2/pig and only marketed once at the end of the study. Overall ADG and ADFI were not different ($P > 0.05$) between these three treatments. Marketing pigs 3 or 4 times improved ($P < 0.05$) G:F compared with the treatment that began the study with 0.71 m^2/pig and

marketed only once. Reducing floor space allowance for heavy weight pigs decreased intake, which resulted in lower growth rate and final BW, with these reductions occurring before the critical *k*-value was reached. Total weight gain per pen was maximized with the lowest space allowance and the multiple marketing treatments. Thus, strategic use of pig removals prior to final marketing may allow producers to maximize both number of pigs and total weight marketed through a barn when feeding to heavy weights.

INTRODUCTION

In the United States, average pig market weight has increased over the past several years and averaged 128 kg during 2018 (NASS, 2018). The long-term pattern of increased market weight is expected to continue in the future. Literature regarding the growth and management of heavy pigs is limited, especially that which evaluates pigs from modern genetic lines housed in a commercial environment. Wu et al. (2017) outlined the current understanding of raising pigs to heavier market weights and identified animal housing, specifically floor space allowance, as a critical area of future research.

Space allowance is an important production input that impacts pig performance, welfare, and producer profitability. Space requirements are often referenced in regard to the *k*-value established by Gonyou et al. (2006), where *k* is an allometric function expressed as k = area, m^2 /$BW^{0.67}$, kg. The authors estimated that every decrease in *k* below 0.0336, or the critical *k*-value, will result in decreased average daily gain (**ADG**) and average daily feed intake (**ADFI**) for grow-finish pigs (Gonyou et al., 2006). While Flohr et al. (2016) concluded the *k*-value defined by Gonyou et al. (2006) was a valid predictor of the impacts of space allowance on growth performance for pigs raised up to 140 kg, others reported that the *k*-value may underestimate the

space allowance needed before growth performance is reduced (Potter et al., 2010; Thomas et al., 2017; Carpenter et al., 2018).

In addition to adjusting the initial stocking density of a pen, topping (or removal of the heaviest pigs from the pen prior to final marketing) is a strategy that can be implemented to provide finishing pigs increased floor space. The additional space in the pen and time before harvest allows the remaining pigs to reach the target market weight and provides increased product consistency at the packing plant, resulting in fewer packer discounts due to variation (Woodworth et al., 2000). Further, these remaining pigs may demonstrate compensatory growth after the period of limited feed intake due to restricted feeder access caused by increased pen stocking density (Flohr et al., 2016). Ultimately, topping strategies are used to maximize facility space while minimizing reduced performance from high pen stocking rates.

Data demonstrating the impact of stocking density and marketing strategy is limited when pigs are fed to heavy weights. Therefore, the objective of this study was to examine the effects of floor space allowance and marketing strategy on the growth performance of pigs raised to 160 kg and evaluate growth performance at heavy weights.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at a commercial research facility (Holden Farms, Inc., Northfield, MN). The barn was double-curtain sided with completely slatted concrete flooring and deep pits for manure storage. Each pen (3.05 × 5.48 m) was equipped with adjustable gates and contained a 3-hole, dry feeder with each space being 38.1 cm wide (Thorp Equipment, Inc., Thorp, WI) and a double-sided pan waterer. Feed additions were

delivered and recorded using a robotic feeding system (FeedPro; ComDel Innovation., Willmar, MN).

Live Animal Management

A total of 976 pigs (PIC 327 × Camborough; PIC, Hendersonville, TN; initially 22.0 ± 1.53 kg body weight [**BW**]) were used in the 160-d growth study. Pens were blocked by location within the barn and randomly assigned within block to 1 of 6 space allowance treatments (Table 1). The first four treatments consisted of increased initial stocking density and did not utilize multiple marketing strategies: 1) 14 pigs/pen (1.17 m^2/pig), 2) 17 pigs/pen (0.97 m^2/pig), 3) 20 pigs/pen (0.82 m^2/pig), and 4) 23 pigs/pen (0.71 m^2/pig). The fifth treatment began with 25 pigs/pen (0.66 m^2/pig) and had 4 marketing events with the heaviest 3 pigs/pen removed on d 93, and additional pigs marketed to achieve common inventories of 20 and 17 pigs/pen on d 122 and 147, respectively. Final marketing occurred on d 160. The final treatment began the experiment with 23 pigs/pen (0.71 m^2/pig) with 3 marketing events to achieve a common inventory of 20 pigs/pen on d 108 and 17 pigs/pen on d 147 with final marketing on d 160.

Pens of pigs were weighed and feed disappearance was measured on d 0, 93, 108, 122, 135, 147, and 160 to determine ADG, ADFI, and feed efficiency (**G:F**). In the case of a pig removal due to illness or death, pen gates were adjusted to maintain the desired floor space allowance. An additional response criteria of adjusted G:F was calculated to adjust to a common BW of 166 kg by using an adjustment of 0.005 for every 0.45 kg difference in BW according to Gaines et al. (2012).

Pigs were given ad libitum access to feed and water throughout the study. Diets were corn- and soybean meal-based and included 30 to 40% corn distillers dried grains with solubles until the final dietary phase. Diets were fed in 6 sequential phases from approximately 21 to 32,

32 to 54, 54 to 83, 83 to 105, 105 to 122, and 122 kg until the end of the study. Diets were formulated to meet or exceed NRC (2012) requirement estimates for finishing pigs and contained 1.18, 1.03, 0.88, and 0.78, 0.76, and 0.77% standardized ileal digestible Lysine in phases 1 through 6, respectively based on a required SID Lys:net energy value. All diets were fed in meal form and manufactured at a commercial feed mill (Blooming Prairie, MN).

Statistical Analysis

Data were analyzed as a randomized complete block design using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC) with the fixed effect of treatment, random effect of block, and pen as the experimental unit. There were 8 replicate pens per treatment. Linear and quadratic contrasts were applied for the four treatments without multiple marketing events, and PROC IML provided coefficients to account for unevenly spaced floor space allowances. Preplanned contrast statements were designed to compare the two multiple removal strategies to each other and to the treatment initially stocked at 0.71 m^2/pig with only one marketing event. Results were considered significant at $P \leq 0.05$.

RESULTS

Adjusting floor space via initial pen stocking inventory

The four treatments that utilized fixed pen inventories to decrease floor space per pig were evaluated using linear and quadratic contrast statements (Table 2). There was no evidence for floor space differences on d 0 or d 55 BW ($P > 0.192$); however, BW was decreased as floor space was reduced (linear, $P < 0.008$) on d 93, 108, 122, 135, 147, and 160.

As floor space allowance was decreased from 1.17 to 0.71 m^2/pig, ADG was also reduced (linear, $P < 0.028$) during d 0 to 55, d 55 to 93, d 108 to 122, d 122 to 135, and for the overall period. Average daily feed intake decreased (linear, $P < 0.027$) as floor space allowance was

reduced during all growth periods and for the overall experimental period. This occurred prior to many treatments reaching the critical *k*-value (Table 3). There was no evidence that decreasing floor space allowance impacted G:F during any intermediate growth period ($P > 0.080$), however, G:F and adjusted G:F was improved with decreasing space allowance during the overall period (quadratic, $P = 0.042$).

Although removals were numerically increased with decreasing floor space, high variation resulted in no evidence ($P > 0.131$) for differences in removals with the static inventory treatments. Furthermore, total weight gain was increased ($P = 0.001$) on a pen basis and decreased ($P = 0.001$) on a per pig basis as stocking density increased.

Adjusting floor space via pig removal

The treatments that incorporated multiple marketing events were evaluated in comparison to each other and to the treatment that was stocked at 0.71 m^2/ pig with only 1 marketing event. There was no evidence that BW ($P > 0.05$) was different on d 0, 93, 122, 135, 147, or 160. However, on d 108, pigs initially allowed 0.71 m^2/pig with only one marketing event were heavier ($P < 0.05$) than pigs initially allowed 0.66 m^2/pig with multiple marketing events, with pens initially stocked at 0.71 m^2/pig with multiple marketing events intermediate.
From d 0 to 93 (pre-marketing period), there was no evidence ($P > 0.05$) that ADG, ADFI, or G:F were different between the two treatments with multiple marketing events or compared to the pens stocked at 0.71 m^2/pig.

From d 93 to 108, after pens originally stocked at 0.66 m^2/pig had their first marketing event, there was no evidence for differences in ADG or ADFI ($P > 0.05$). However, after the heaviest pigs were marketed from the pens initially stocked at 0.66 m^2/pig, these pigs

demonstrated improved ($P < 0.05$) G:F compared to both treatments initially stocked at 0.71 m^2/pig, regardless of marketing strategy, which were not different from each other ($P > 0.05$).

The treatment originally stocked at 0.71 m^2/pig with 3 marketing events was topped to 20 pigs for the first time on d 108, yet there was no evidence for differences ($P > 0.05$) in ADG, ADFI, or G:F from d 108 to 122.

The next marketing event occurred for the pens initially allowed 0.66 m^2/pig, which were marketed for the second time to 20 pigs/pen on d 122. From d 122 to 135, both treatments with multiple marketing events demonstrated increased ($P < 0.05$) ADG compared to the treatment that allowed 0.71 m^2/pig with only one marketing event at the end of the study, yet they were not different from each other ($P > 0.05$). There was no evidence ($P > 0.05$) that ADFI or G:F differed from d 122 to 135 between these treatments.

There were no marketing events on d 135. However, pens initially stocked at 0.66 m^2/pig that had two marketing events prior to that point in time demonstrated increased ($P < 0.05$) ADG from d 135 to 147 compared to both treatments that began with 0.71 m^2/pig, regardless of marketing strategy. Pens that began with 0.71 m^2/pig and had been marketed once up to this point also had increased ($P < 0.05$) ADG compared to their counterparts that were only to be marketed once at the end of the study. Although this response was not exhibited directly after the removal of the heaviest pigs for market, this appears to be a compensatory gain response. During d 135 to 147, both treatments with multiple marketing events had increased ($P < 0.05$) ADFI compared to the treatment with 0.71 m^2/pig that had no pigs removed prior to the final marketing event, yet were not different from each other ($P > 0.05$). Feed efficiency was improved ($P < 0.05$) for pens of pigs that had been marketed twice and initially stocked at 0.66 m^2/pig compared

both to pens stocked at 0.71 m^2/pig that were either only marketed once at the end of the study and those marketed once up to this point, which were not different from each other ($P > 0.05$).

The last marketing events occurred for both multiple marketing treatments on d 147, at which point both treatments had 17 pigs/pen remaining. From d 147 to 160, there was no evidence of difference in ADG and G:F ($P > 0.05$). Average daily feed intake was increased ($P < 0.05$) for pens of pigs stocked at 0.71 m^2/pig and marketed multiple times compared to pens of pigs only marketed once at the end of the study, yet similar ($P > 0.05$) to the other multiple marketing treatment. There was no evidence ($P < 0.05$) that pens of pigs allowed 0.71 m^2/pig with no previous marketing events had different ADFI than those allowed 0.66 m^2/pig but were marketed 3 times.

There was no evidence that overall ADG or ADFI differed between these three treatments ($P > 0.05$). Feed efficiency and adjusted G:F was improved ($P < 0.05$) for pigs initially stocked at 0.66 m^2/pig and marketed four times compared to both treatments initially stocked at 0.71 m^2/pig, regardless of marketing strategy. Additionally, overall G:F and adjusted G:F was improved ($P < 0.05$) for pigs that began at 0.71 m^2/pig and were marketed 3 times compared to the treatment that also began at 0.71 m^2/pig but only marketed at the end of the study.

Once marketing began on d 93, ADG and G:F were improved ($P < 0.05$) for the remainder of the trial (d 93 to 160) for both multiple marketing treatments compared to the 0.71 m^2/pig allowance with only one marketing event at the end of the study, but were not different ($P > 0.05$) from each other.

Removals and total weight gain per pen did not differ between these three treatments ($P > 0.05$). However, total weight gain per pig was greater ($P < 0.05$) for pigs originally stocked at

0.71 m^2/pig with only one marketing event at the end of the study compared to both multiple marketing treatments. Furthermore, marketing three times with initial stocking density of 0.71 m^2/pig increased ($P < 0.05$) total weight gain per pig compared to marketing four times.

Feed intake and growth rate to 160 kg

Figures 1 and 2 depict BW and cumulative feed intake (FI) by d of experiment. Slight reductions in anticipated BW and feed intake observed at d 108 correspond to a PRRS outbreak. However, growth rate past current market weights and capacity for feed consumption was noteworthy. At approximately 155 kg, pigs were gaining 0.92 kg/d. From 22 to 160 kg, pigs consumed over 400 kg of feed per pig, with intake still increasing at the end of the experiment. Figures 3 and 4 depict ADG and ADFI by body weight, respectively. Growth rate appears to be maximized between around 100 kg BW, but ADFI continued to increase to 165 kg.

DISCUSSION

Live market weights for swine have increased over the past several decades and averaged 128 kg in 2018 (NASS, 2018). If historical trends continue, market weights in the United States could exceed 150 kg by 2050. Growth rate has also increased over time due to genetic selection and greater understanding of nutritional requirements. Producers are motivated to increase market weight in order to dilute fixed facilities cost (Park and Lee, 2011).

Floor space allowance is an important metric to consider when raising pigs to heavy weights. Space is a complex parameter in swine production due to the inverse relationship between profitability and growth performance (Gonyou et al., 2006). A majority of the fundamental research regarding space requirements for grow-finish pigs was conducted several decades ago with different genetics and lighter market weights than modern production standards. The consistent finding from this literature is that floor space restriction decreases

ADFI, which drives a reduction in ADG (NCR-89 Committee on Confinement Management of Swine, 1993; M. C. Brumm and NCR-89 Committee on Management of Swine, 1996; Gonyou and Stricklin, 1998). Using available literature, Gonyou et al. (2006) performed a meta-analysis to establish an equation (A, $m^2 = k \times [BW^{0.67}, kg]$) that describes pig BW as an allometric function by which ADG and ADFI may be reduced if the *k*-value is below 0.0336, or the critical *k*-value. This equation is a useful tool for understanding the impact of space allowance on the growth performance of pigs raised in commercial environments. However, final BW in Gonyou et al. (2006) did not exceed 110 kg and, thus, the application of this equation may become limited as market weights continue to increase.

Recent research evaluating space allowance (either by changing pen inventory or adjustable gating) for pigs raised to modern market weights continues to report decreased growth rate as a consequence of reduced feed intake (Johnston et al., 2017; Thomas et al., 2017; Carpenter et al., 2018). Thomas et al. (2017) and Carpenter et al. (2018) reduced floor space in pens with fixed inventories and observed decreased ADG and ADFI, with these reductions occurring from approximately 70 kg, or prior to reaching the critical *k*-value. Body weight was used to calculate *k*-value for all weigh days in the present study (Table 3). Interestingly, ADG was decreased among static inventory treatments as early as d 55 (approximately 67 kg) due to reduced feed intake as floor space decreased. This immediate impact was not anticipated given that the *k*-value was greater than 0.0336 for all treatments, with the exception of the pens providing 0.71 m^2/pig, which only would have been limited near the end of this period. The treatment that allowed 1.17 m^2 per pig was never below the critical *k*-value even at 171 kg. Treatments that provided 0.97, 0.82 or 0.71 m^2 for the entire experiment became limiting at 155, 130, and 105 kg, respectively. However, growth was impaired compared to the treatment with

the highest space allowance prior to reaching 105 kg during d 0 to 93. Thus, these results align with the aforementioned experiments (Thomas et al., 2017; Carpenter et al., 2018) and indicate that the *k*-value may underestimate the point at which growth performance is compromised.

Economic response criteria were not evaluated in the current experiment due to the pigs being heavier than current packer specifications, yet total weight gain per pen was maximized at the lowest space allowance and the treatments with multiple marketing events. This response demonstrates that having more pigs in the pen or barn will consistently yield increased revenue strictly due to the quantity of pork produced, which is in agreement with findings by Flohr et al. (2016) where income over fixed facilities cost was increased with increased stocking density. However, multiple marketing strategies can help reduce market weight variation.

Unlike growth rate and feed intake, the effects of space allowance on feed efficiency in the literature are more variable. Several have reported no evidence for differences (Johnston et al., 2017; Thomas et al., 2017; Carpenter et al., 2018), while others observed poorer G:F with floor space restriction (NCR-89 Committee on Confinement Management of Swine, 1993; M. C. Brumm and NCR-89 Committee on Management of Swine, 1996; Street and Gonyou, 2008). Hypothesized mechanisms for reduction in feed conversion accompanying floor space restriction include decreased protein deposition (Chapple, 1993) and increased activity and trips to the feeder in crowded pens (Shull, 2010). Further, feed efficiency can be confounded with increased BW for pigs provided ample floor space. In the present study, there were negligible G:F effects observed during intermediate periods, yet overall G:F improved slightly with decreasing floor space. This was likely due to lower ending BW because when G:F adjusted for BW was not different. This could be explained by feed restriction decreasing feed wastage and therefore,

increasing efficiency of gain (Patience et al., 2015). When adjusted to a final body weight of 166 kg, G:F also improved slightly with restricted space allowance.

Johnston et al. (2017) conducted a cooperative experiment to evaluate the space requirement for heavy weight pigs and suggest that 0.98 m^2/pig is necessary for pigs weighing 130 kg due to little evidence of improved growth performance beyond this space allowance. The current data display continued linear improvement in ADG and ADFI up to 1.17 m^2/pig, suggesting that the point at which floor space would no longer improve performance was not reached. The difference between the response observed in the present study and Johnston et al. (2017) may have been an effect of the smaller group size within pen (6 to 19 pigs) used in Johnston et al. (2017). As market weights continue to increase, more space may be needed and multiple marketing techniques should continue to be investigated at heavy weights to maximize performance and space utilization.

Other authors have studied increasing space allowance in late finishing with pig removal strategies, commonly referred to as "topping" (DeDecker et al., 2005; Jacela et al., 2009; Flohr et al., 2016). Topping involves removal of the heaviest pigs one or more times prior to marketing of the entire pen or barn as they reach the optimal market weight, which allows the remaining pigs extra time and space to reach market weights. Woodworth et al. (2000) and Carpenter et al. (2018) demonstrated that pigs remaining in the pen after the heaviest are removed have increased rate of gain. This improvement in growth rate may be attributed to decreased competition for resources such as feeder space, waterer space, and resting area within the pen, as well as improved social hierarchy with the removal of large pigs (Flohr et al., 2016; Johnston et al., 2017). Similarly, DeDecker et al. (2005) removed varying proportions of pen inventory during the final 19 d of the finishing period and concluded that removing 25 or 50% of the pen resulted

in increased performance of remaining pigs compared to pens with no removal. Flohr et al. (2016) increased floor space allowance via one, two, or three marketing events prior to the final marketing event and observed similar results. In the current experiment, feed efficiency of pigs remaining in the pen after topping occurred was improved, which is in agreement with the aforementioned literature and an indicator of increased efficiency of gain associated with compensatory growth (DeDecker et al., 2005; Jacela et al., 2009; Flohr et al., 2016).

Recently, Flohr et al. (2018) reviewed available literature and developed multivariate equations to predict ADG and ADFI as a function of initial BW, final BW, and *k*-value. According to this model, increasing floor space among the static inventory treatments used in this experiment yields a 7% and 6% improvement in ADG and ADFI, respectively (Flohr et al., 2018). The actual improvements were 7% for ADG and 7% for ADFI when increasing floor space from 0.77 to 1.17 m^2/pig. The equations of Flohr et al. (2018) appear to be robust indicators of expected growth outcomes when providing space allowance for pigs at heavy market weights.

Pigs are typically marketed as they approach the inflection point of their growth curve, or the point at which their growth rate begins to plateau (Shull, 2013). However, intensive selection for lean genetic lines has likely extended this growth curve and increased the capacity for lean growth at heavy weights. Shull (2013) developed growth curves for modern-type pigs raised to 170 kg in a commercial setting and observed that ADG and ADFI peaked at 76 and 118 kg, respectively. Pigs in the current experiment did not plateau until approximately 100 kg for ADG, which is a heavier BW than other researchers have reported (Schinckel et al., 2006; Shull, 2013). This observation reiterates the progress made via genetic selection and the potential for efficient protein deposition at weights exceeding current production practices. Additionally, pigs in the

present study did not display evidence that rate of ADFI was diminishing, even at 160 kg. Therefore, increased input costs and pressure on feed manufacturing processes will need to be considered as market weights increase.

In conclusion, these results demonstrate that floor space restriction reduces intake and, consequently, growth rate. The impact of reducing floor space allowance for pigs raised to heavy market weights is seen as early as 100 kg, or before reaching the critical *k*-value (0.0336). However, utilization of multiple marketing events provides producers a means to maximize stocking density and total weight marketed while mediating reduced performance. Lastly, efficient rate of gain appears to be achievable at weights heavier than current market standards, highlighting the progress made via continued genetic selection for lean-type pigs, but also potential lost opportunity with current market weight targets.

LITERATURE CITED

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Table 1-1. Diet composition, as-fed[1]

	BW range, kg					
Item	21 to 32	32 to 54	54 to 82	82 to 105	105 to 122	122 to 167
Ingredient, %						
Corn	39.39	47.08	55.49	60.74	60.52	82.76
Soybean meal, 46.5% crude protein	17.40	9.80	6.58	6.52	6.92	14.62
Corn distillers dried grains with solubles	40.00	40.00	35.00	30.00	30.00	---
Monocalcium phosphate, 21% P	0.20	0.15	0.10	0.10	0.09	0.50
Limestone	1.30	1.25	1.20	1.20	1.15	0.78
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Copper sulfate	0.03	0.03	0.03	---	---	---
L- lysine HCl	0.58	0.63	0.55	0.45	0.40	0.30
DL-methionine	0.02	---	---	---	0.00	0.05
L-threonine	0.09	0.09	0.07	0.05	0.04	0.12
L-tryptophan	0.04	0.05	0.04	0.04	0.04	0.03
Vitamin and trace mineral premix[1]	0.25	0.20	0.20	0.15	0.10	0.10
Phytase[2]	0.08	0.08	0.10	0.10	0.10	0.10
Sodium metabisulfite	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) AA, %						
Lysine	1.18	1.03	0.88	0.78	0.76	0.77
Isoleucine:lysine, %	63	59	60	64	67	61
Leucine:lysine, %	166	172	183	194	203	149
Methionine:lysine, %	31	30	32	34	36	34
Methionine+Cystine:lysine, %	56	56	60	64	67	61
Threonine:lysine, %	62.0	60.7	60.7	63.0	64.9	67.6
Tryptophan:lysine, %	18.3	18.3	17.8	19.3	19.7	19.7
Val:lysine, %	74	72	75	80	84	70
Net energy[3], kcal/kg	2,385	2,434	2,469	2,487	2,487	2,533
SID lysine:net energy ratio, g/mcal	4.94	4.24	3.56	3.15	3.04	3.06
Crude protein, %	22.9	20.1	17.8	16.7	16.9	14.0

Ca, %	0.63	0.58	0.54	0.53	0.51	0.45
P, %	0.50	0.46	0.42	0.40	0.40	0.42
Available P, %	0.40	0.37	0.35	0.33	0.32	0.29

[1] Provided 1,543,220 IU vitamin A from vitamin A acetate; 440,920 IU vitamin D from vitamin D3; 8,047 IU vitamin E from dl-α-tocophorol acetate; 882 mg menadione from menadione nicotinamide bisulfite; 8 mg B12 from cyanocobalamin; 14,991 mg niacin from niacinamide; 6,614 pantothenic acid from d-calcium panthothenate; 1,984 mg riboflavin from crystalline riboflavin; 3 g Cu from copper sulfate; 160 mg Ca from calcium iodate; 31 mg Fe from ferrous sulfate; 3 g Mn from manganese sulfate; 120 mg Se from sodium selenite; and 31 g Zn from zinc sulfate per kg of premix.

[2] Ronozyme HiPhos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ) provided 1,102,300 phytase units (FTU)/kg of product with a release of 0.10% available P.

[3] NRC. 2012. Nutrient requirements of swine. 11th ed. Natl. Acad. Press, Washington, DC.

Table 1-2. Effects of space allowance and marketing strategy on growth performance of pigs raised to 160 kg[1]

								P-value	
Initial floor space, m^2/pig:	1.17	0.97	0.92	0.71	0.66	0.71			
Final floor space, m^2/pig:	1.17	0.97	0.82	0.71	0.97	0.97			
Initial pigs/pen:	14	17	20	23	25	23		Floor space[4]	
Item Marketing events:	1	1	1	1	4[2]	3[3]	SEM	Linear	Quadratic
BW, kg									
d 0	22.2	22.1	22.2	22.2	21.8	21.9	0.57	0.994	0.926
d 55	69.2	67.9	67.4	67.8	66.3	66.1	1.06	0.192	0.464
d 93	108.7	106.2	105.5	104.7	103.3	103.5	1.49	0.008	0.610
d 108[a]	120.2	116.6	116.1	115.6	111.9	113.9	1.40	0.005	0.276
d 122	134.5	130.4	129.8	128.6	125.7	125.1	1.45	0.002	0.397
d 135	147.7	143.1	142.1	140.2	137.7	137.8	1.34	0.001	0.527
d 147	159.5	155.1	154.2	151.5	150.8	149.8	1.46	0.001	0.814
d 160	171.1	167.2	165.5	162.6	160.3	161.7	1.59	0.001	0.925
d 0 to 55									
ADG, kg	0.85	0.83	0.82	0.83	0.81	0.80	0.011	0.028	0.138
ADFI, kg	1.93	1.86	1.83	1.86	1.80	1.79	0.031	0.022	0.108
G:F	0.443	0.447	0.448	0.446	0.450	0.446	0.0039	0.452	0.467
d 55 to 93									
ADG, kg	1.02	1.01	1.00	0.98	0.97	0.98	0.019	0.006	0.474
ADFI, kg	3.00	2.91	2.89	2.85	2.78	2.83	0.035	0.001	0.543
G:F	0.341	0.0346	0.347	0.342	0.349	0.346	0.0048	0.614	0.108
d 93 to 108									
ADG, kg	0.75	0.67	0.69	0.71	0.77	0.69	0.031	0.231	0.057
ADFI, kg	2.66	2.51	2.50	2.53	2.47	2.44	0.050	0.027	0.086
G:F[a,c]	0.283	0.268	0.275	0.281	0.311	0.280	0.0111	0.893	0.141
d 108 to 122									
ADG, kg	1.02	0.95	0.94	0.93	0.97	0.95	0.023	0.005	0.342
ADFI, kg	3.59	3.26	3.26	3.19	3.24	3.25	0.059	0.001	0.054
G:F	0.285	0.291	0.289	0.290	0.299	0.293	0.0064	0.520	0.654
d 122 to 135									
ADG, kg[a,b]	1.02	0.97	0.90	0.88	0.96	0.96	0.033	0.001	0.918

ADFI, kg	3.63	3.42	3.35	3.28	3.38	3.36	0.050	0.001	0.459
G:F	0.282	0.284	0.269	0.269	0.285	0.287	0.0079	0.080	0.496
d 135 to 147									
ADG, kg[a,b,c]	0.98	1.00	1.00	0.91	1.09	1.00	0.028	0.165	0.052
ADFI, kg[a,b]	3.68	3.57	3.43	3.30	3.57	3.53	0.052	0.001	0.297
G:F[a,c]	0.267	0.280	0.291	0.277	0.306	0.284	0.0067	0.095	0.084
d 147 to 160									
ADG, kg	0.90	0.93	0.87	0.84	0.86	0.98	0.047	0.145	0.183
ADFI, kg[b]	3.81	3.71	3.56	3.47	3.63	3.77	0.116	0.001	0.583
G:F	0.235	0.249	0.245	0.240	0.237	0.259	0.0076	0.588	0.138
d 0 to 160									
ADG, kg	0.93	0.90	0.89	0.87	0.89	0.88	0.008	0.001	0.713
ADFI, kg	2.81	2.68	2.64	2.62	2.56	2.59	0.031	0.001	0.169
G:F[a,b,c]	0.329	0.335	0.336	0.333	0.348	0.340	0.0023	0.096	0.042
Adjusted G:F[5,a,b,c]	0.332	0.336	0.336	0.332	0.345	0.338	0.0021	0.907	0.034
Marketing period (d 93 to 160)									
ADG, kg[a,b]	0.93	0.89	0.87	0.85	0.92	0.90	0.013	0.001	0.941
ADFI, kg	3.45	3.26	3.19	3.13	3.21	3.20	0.038	0.001	0.314
G:F[a,b]	0.270	0.275	0.274	0.271	0.288	0.281	0.0033	0.637	0.159
Removals, %	2.6	7.2	7.3	5.8	7.8	7.4	2.4	0.182	0.131
Total weight gain, kg/pen	2,022	2,258	2,621	2,985	2,986	2,870	95.4	0.001	0.080
Total weight gain, kg/pig[a,b,c]	148	143	141	139	131	135	1.4	0.001	0.691

[a] Pigs stocked at 0.71 m^2/pig with one marketing event vs. pigs initially stocked at 0.66 m^2/pig with 4 marketing events are significantly different ($P < 0.05$).

[b] Pigs stocked at 0.71 m^2/pig with one marketing event vs. pigs initially stocked at 0.71 m^2/pig with 3 marketing events are significantly different ($P < 0.05$).

[c] Pigs stocked at 0.66 m^2/pig with 4 marketing events vs. pigs initially stocked at 0.71 m^2/pig 3 marketing events are significantly different ($P < 0.05$).

[1]A total of 976 finishing pigs (initially 22.1 ± 1.53 kg) were used in a 160-d experiment to evaluate the effects of pig space allowance and marketing strategy on finishing pigs raised to heavier weights.

[2] Three of the heaviest pigs/pen were removed on d 93. The heaviest pigs were also removed to achieve a common pen inventory of 20 pigs/pen on d 122 and 17 pigs/pen on d 147.

[3] The heaviest pigs were removed on to reach a common pen inventory of 20 pigs/pen on d 108 and 17 pigs/pen on d 147.

[4] Treatments 1 through 4 were evaluated using the linear and quadratic contrasts.
[5] Calculated as Adjusted G:F = 1/[(observed feed:gain ratio)+((22.7-initial BW)×0.005) + ((165.5-final BW)×0.005) according to an equation by Gaines et al. (2012).

Table 1-3. Determination of *k*-values for different space allocations and pig weights[1,2]

	Initial floor space, m^2/pig:	1.17	0.97	0.92	0.71	0.66	0.71
	Final floor space, m^2/pig:	1.17	0.97	0.82	0.71	0.97	0.97
	Initial pigs/pen:	14	17	20	23	25	23
Item	Marketing events:	1	1	1	1	4	3
d 0							
BW, kg		22.2	22.1	22.2	22.1	21.8	21.9
m^2/pig		1.17	0.97	0.82	0.71	0.66	0.71
k-value[5]		0.1471	0.1215	0.1028	0.0896	0.0834	0.0903
d 55							
BW, kg		69.2	67.9	67.4	67.8	66.3	66.1
m^2/pig		1.17	0.97	0.82	0.71	0.66	0.71
k-value		0.0686	0.0572	0.0489	0.0424	0.0403	0.0440
d 93							
BW, kg		108.7	106.2	105.6	104.7	103.2	103.5
m^2/pig		1.17	0.97	0.82	0.71	0.66	0.71
k-value		0.0507	0.0424	0.0362	**0.0316**	**0.0300**	**0.0326**
m^2/pig after marketing		---	---	---	---	0.81	---
k-value after marketing		---	---	---	---	0.0364	---
inventory after marketing		---	---	---	---	20.2	---
d 108							
BW, kg		120.2	116.6	116.1	115.6	111.9	113.9
m^2/ pig		1.17	0.97	0.82	0.71	0.81	0.71
k-value		0.0474	0.0398	0.0340	**0.0296**	0.0345	**0.0306**
m^2/pig after marketing		---	---	---	---	---	0.82
k-value after marketing		---	---	---	---	---	**0.0344**
inventory after marketing		---	---	---	---	---	20
d 122							
BW, kg		134.4	130.4	129.8	128.6	125.7	125.1
m^2/pig		1.17	0.97	0.82	0.71	0.81	0.82
k-value		0.0440	0.0370	**0.0315**	**0.0276**	**0.0319**	**0.0323**

m^2/pig after marketing	---	---	---	---	0.82	---
k-value after marketing	---	---	---	---	**0.0322**	---
inventory after marketing	---	---	---	---	20	---
d 135						
BW, kg	147.7	143.1	142.1	140.2	137.7	137.8
m^2/pig	1.17	0.97	0.82	0.71	0.82	0.82
k-value	0.0413	0.0347	**0.0297**	**0.0260**	**0.0303**	**0.0303**
d 147						
BW, kg	159.4	155.1	154.2	151.5	150.7	149.8
m^2/pig	1.17	0.97	0.82	0.71	0.82	0.82
k-value	0.0392	**0.0329**	**0.0281**	**0.0247**	**0.0285**	**0.0286**
m^2/pig after marketing	---	---	---	---	0.97	0.97
k-value after marketing	---	---	---	---	**0.0335**	0.0337
inventory after marketing	---	---	---	---	17	17
d 160						
BW, kg	171.1	167.2	165.5	162.6	160.3	161.7
m^2 / pig	1.17	0.97	0.82	0.71	0.97	0.97
k-value	0.0374	**0.0313**	**0.0268**	**0.0236**	**0.0322**	**0.0320**

[1] A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-d experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

[2] Values in bold represent *k*-values below the critical *k*-value of 0.0336 as described by Gonyou et al. (2006).

[3] Three of the heaviest pigs/pen were removed on d 93. The heaviest pigs were also removed to achieve a common pen inventory of 20 pigs/pen on d 122 and 17 pigs/pen on d 147.

[4] The heaviest pigs were removed to reach a common pen inventory of 20 pigs/pen on d 108 and 17 pigs/pen on d 147.

[5] Defined as A, $m^2 = k \times (BW^{0.67}$, kg) as defined by Gonyou et al. (2006).

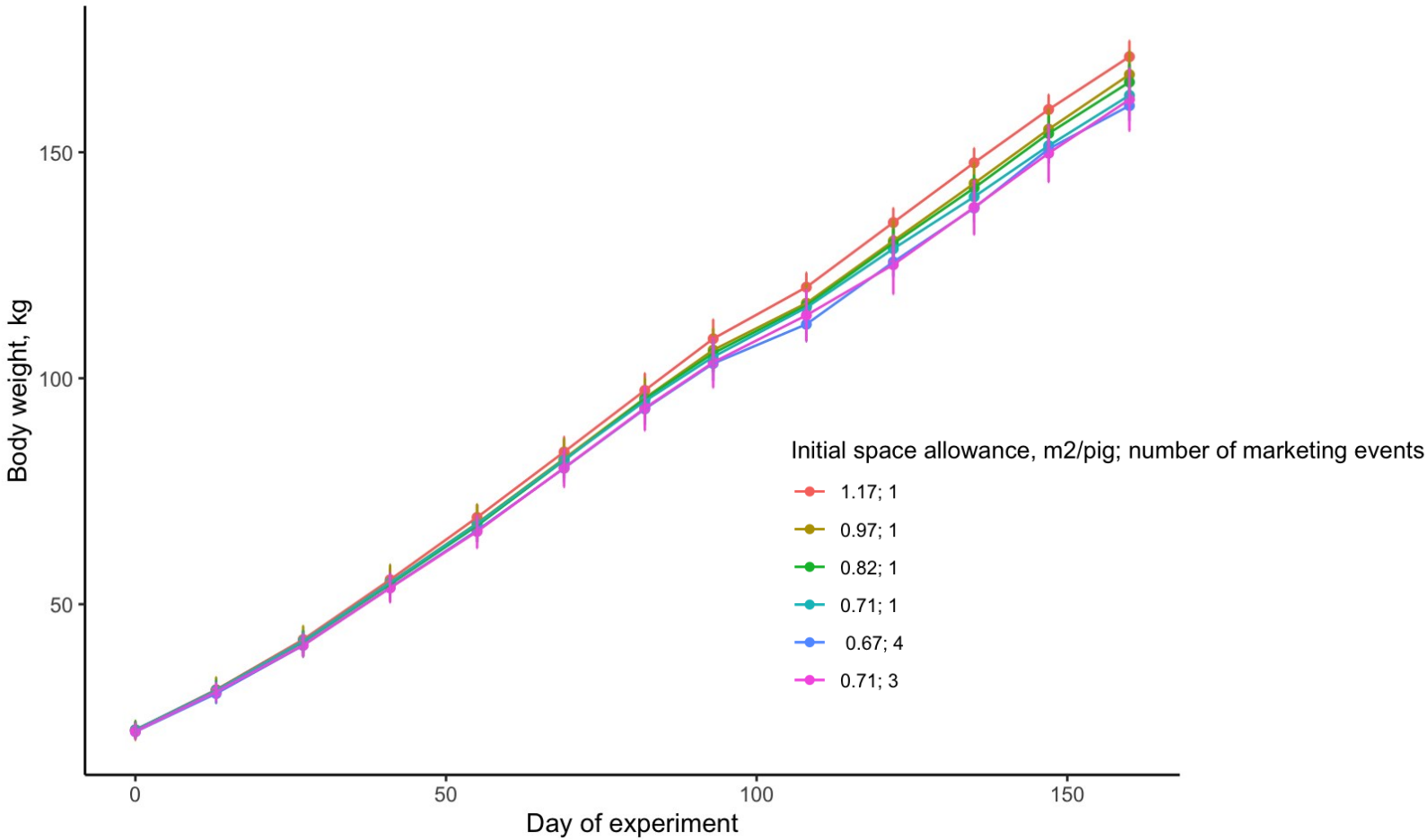

Figure 1-1. Body weight by day of experiment for six treatments differing in initial space allowance and marketing strategy. A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-d experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

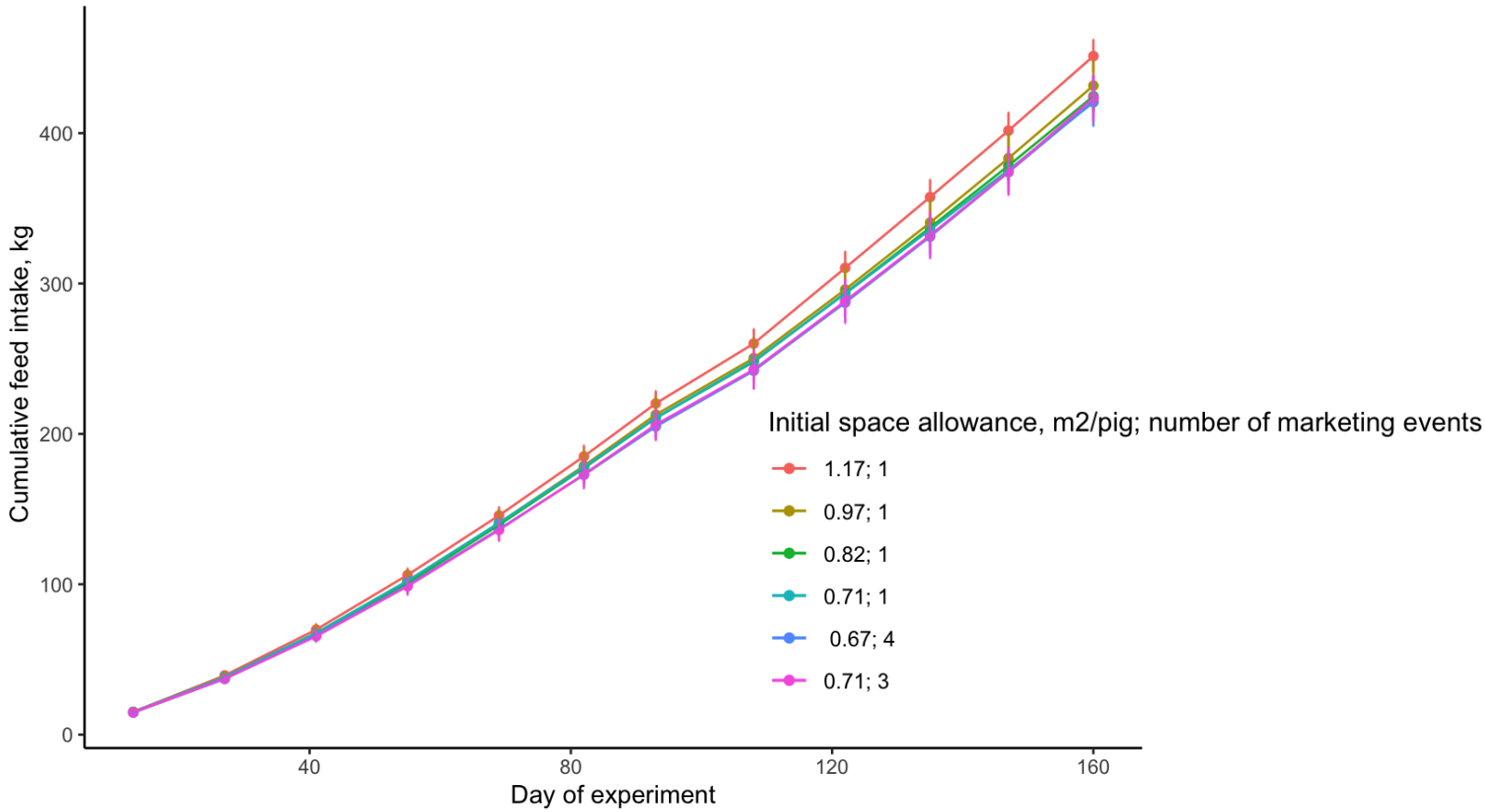

Figure 1-2. Cumulative feed intake by day of experiment for six treatments differing in initial space allowance and marketing strategy. A total of 976 finishing pigs (22.1 ± 1.53 kg) were used in a 160-d experiment to evaluate the effects of pig space allowance and marketing strategy on growth performance of finishing pigs raised to heavy market weights.

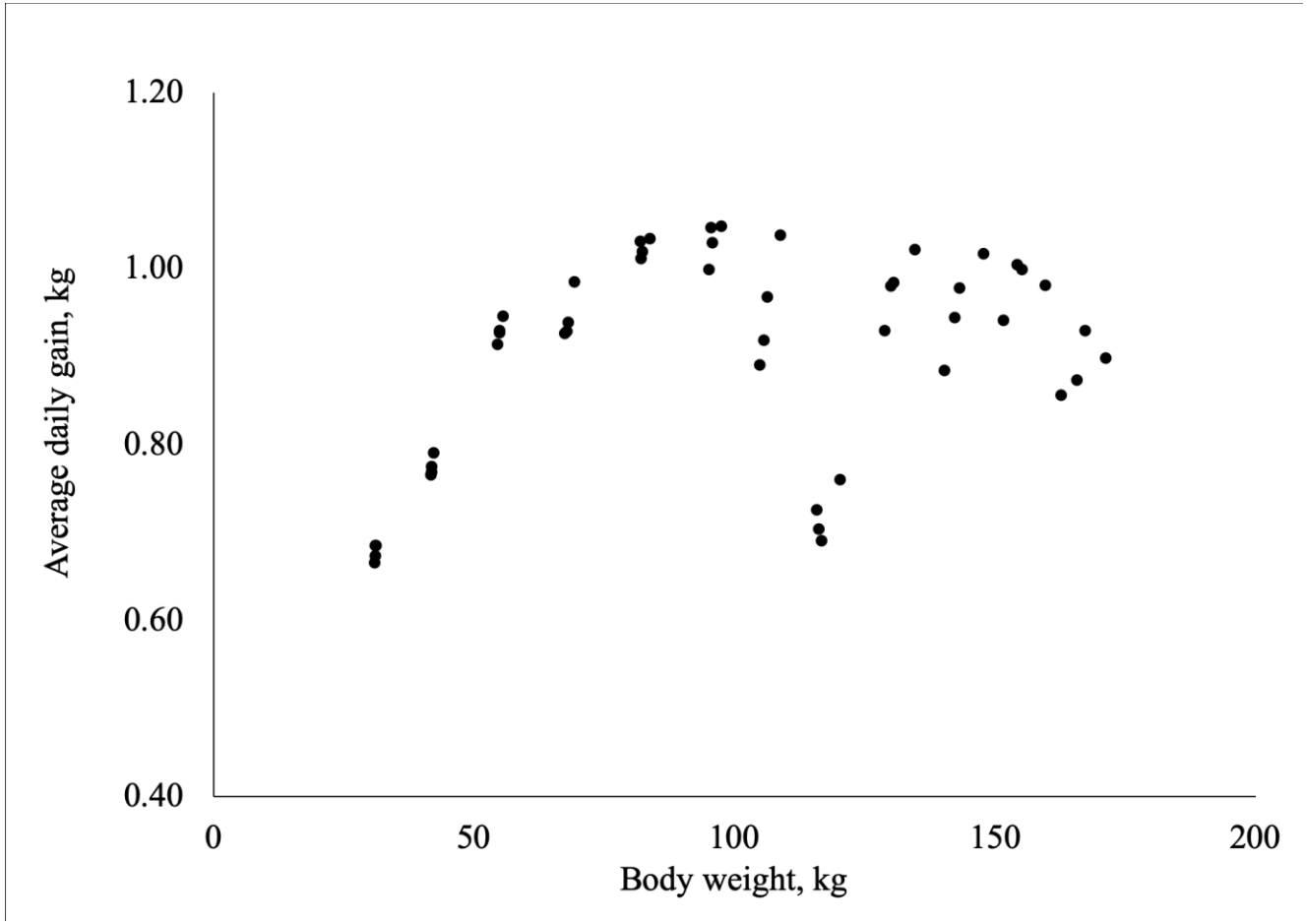

Figure 1-3. Average daily gain from 22 to 160 kg. Data shown represents the means from the four treatments with static pen inventory (provided 0.71 to 1.17 m^2/pig).

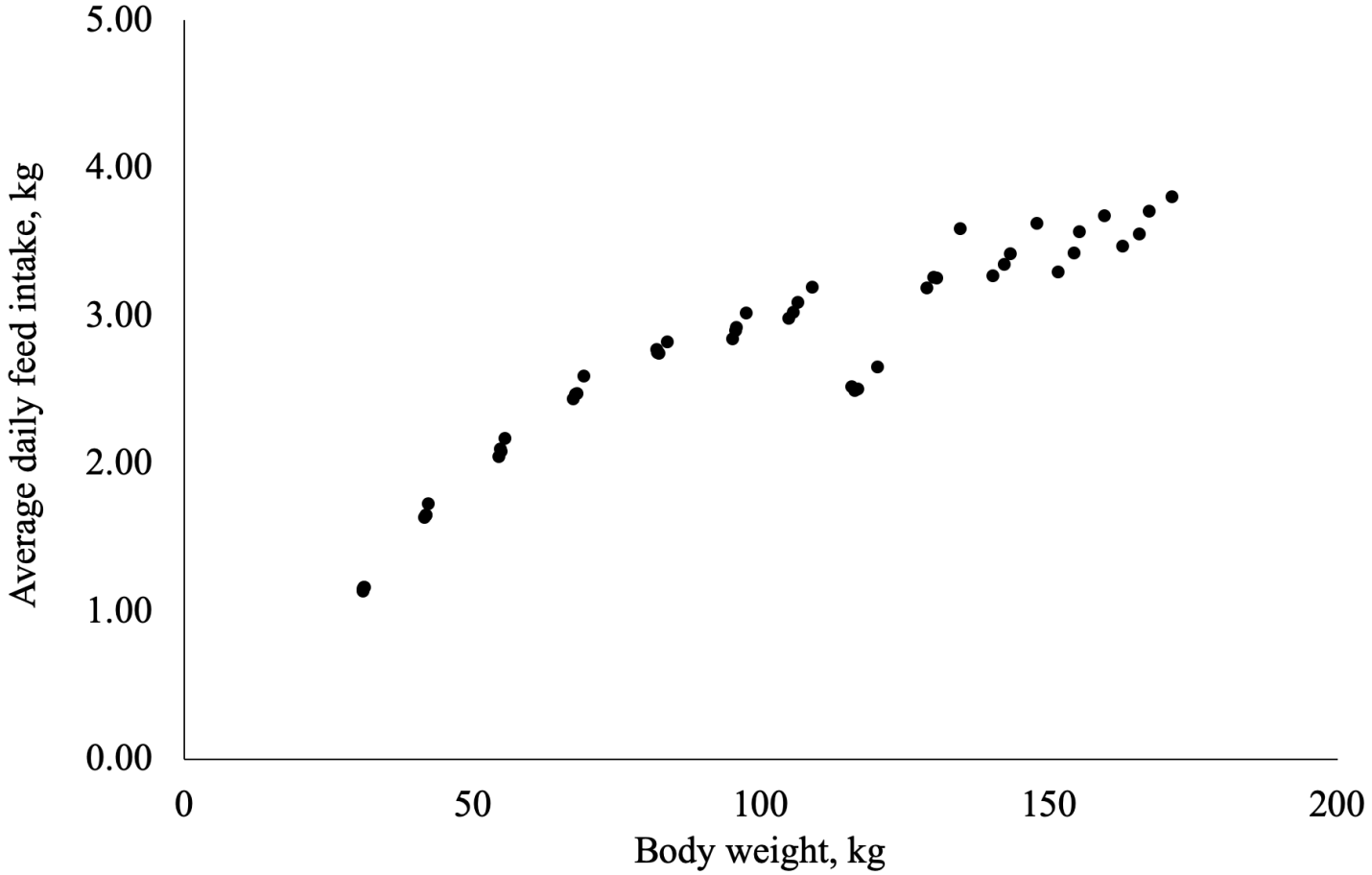

Figure 1-4. Average daily feed intake from 22 to 160 kg. Data represents the first four treatments with static pen inventory. Data shown represents the means from the four treatments with static pen inventory (provided 0.71 to 1.21 m^2/pig).

Chapter 2 - Effects of switching from corn distillers dried grains with solubles- to corn- and soybean meal-based diets on finishing pig performance, carcass characteristics and carcass fatty acid composition

ABSTRACT

Corn distillers dried grains with solubles (**DDGS**) are known to negatively impact carcass yield and fat quality, thus finishing pigs may need to be switched from diets containing DDGS to corn-soybean meal (**CSBM**) diets before marketing. A total of 860 finishing pigs (PIC C48 or L42 × 327; initially 66.2 kg BW) were used in a 76-d experiment to evaluate the effects of switching pigs from DDGS to CSBM diets at increasing intervals before harvest. Pen served as the experimental unit, and there were 7 replicate pens/treatment with 23 to 25 pigs/pen. Pens were blocked by body weight (**BW**) and allotted to 1 of 5 dietary treatments differentiated by the number of days prior to market that diets containing DDGS were replaced with CSBM diets: 76, 42, 27, 15, or 0 d before harvest. Diets contained 40% DDGS prior to the experiment, 0 or 35% DDGS during the experiment from approximately 66 to 82 kg, and 0 or 30% DDGS until the completion of the trial. Diets were not balanced for net energy. Linear and quadratic response to time following dietary switch was evaluated using PROC GLIMMIX. For the overall period (d 76 prior to market to d 0), as time consuming CSBM increased, average daily gain (**ADG**) and final BW increased (linear, $P < 0.002$) and feed efficiency (**G:F**) improved (quadratic, $P = 0.019$). Average daily feed intake increased (quadratic, $P = 0.030$) as time consuming CSBM increased. There was an increase (linear $P = 0.010$) in hot carcass weight (**HCW**), with a

marginally significant increase in carcass yield (linear, $P = 0.094$) with increasing time after the switch to CSBM diets. Loin depth and lean percentage did not demonstrate any evidence for treatment differences ($P > 0.132$). Backfat increased (linear, $P = 0.030$) with increasing time after dietary switch. Lastly, iodine value (**IV**) of belly fat was decreased (linear, $P = 0.001$) with increased feeding duration of CSBM. In conclusion, switching to CSBM for longer periods before slaughter increased ADG and improved G:F, resulting in increased HCW. After diets were switched from DDGS to CSBM, pigs demonstrated an increase in intake, likely due to the ability to consume high volumes of feed after consuming high fiber (DDGS) diets. Belly fat IV was decreased as the length of time after dietary change was increased, with the lowest IV resulting from pigs that consumed CSBM for the entire experimental period.

INTRODUCTION

Corn distillers dried grains with solubles are commonly included in swine diets to partially replace corn and soybean meal. Several studies have demonstrated that the addition of up to 30% corn distillers dried grains with solubles (**DDGS)** does not negatively impact growth rate (DeDecker et al., 2005; Stein and Shurson, 2009). However, increased neutral detergent fiber (**NDF**) in the digestive tract increases gut fill and intestinal weight and therefore can result in reduced carcass yield for pigs consuming high NDF diets compared to their counterparts consuming a diet with lower NDF (Gaines et al., 2007; Soto et al., 2019). In addition to a high NDF content, DDGS also contain increased concentrations of unsaturated fatty acids, which may result in reduced fat quality (Stein and Shurson, 2009; Graham et al., 2014).

Many authors have evaluated the effects of switching from diets containing high NDF to those which contain only corn and soybean meal as the primary protein and energy sources (Asmus et al., 2014; Graham et al., 2014; Coble et al., 2018). Their findings largely conclude

that switching from high NDF to low NDF (corn- and soybean meal-based diets) approximately 24 d before market can mitigate negative impacts on yield, while pork fat firmness as indicated by iodine value may take longer to restore; however, these studies employed both DDGS and wheat middlings to increase NDF. Jacela et al. (2009) determined that a 3- or 6-week period following switch from DDGS to a corn-soy diet did not impact growth performance but significantly improved fatty acid saturation for pigs switched from DDGS as measured by iodine value. In regards to finishing growth performance, some authors have reported improvements following a switch to a lower fiber diet (Asmus et al., 2014; Coble et al., 2018) while some report no change (Hilbrands et al., 2013; Lerner et al., 2019). Therefore, it is important to understand the ideal timing of dietary switch from DDGS-containing to corn- and soybean meal-based diets and the subsequent impact on finishing pig growth performance, carcass characteristics, and carcass fat IV. The objective of this study was to understand the impacts of switching from DDGS to low NDF diets at increasing intervals starting 76 d before harvest in a commercial facility on growth, carcass characteristics, and carcass fatty acid composition.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The trial was conducted at a commercial research facility (Holden Farms, Inc., Northfield, MN). The barn was double-curtain sided with completely slatted concrete flooring and deep pits for manure storage. Each pen (3.05 × 5.48 m) was equipped with adjustable gates and contained a 3-hole, dry feeder with each space being 38.1 cm wide (Thorp Equipment, Inc., Thorp, WI) and a double-sided pan waterer. Feed additions were

delivered and recorded using a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN).

A total of 860 pigs (PIC 327 × C48/L42, Hendersonville, TN; initial average body weight [**BW**] of 66.2 ± 5.03 kg) were used in the 76-d growth study. Pen was the experimental unit, and there were 7 replicate pens per treatment with 23 to 25 pigs per pen. Pens were blocked by BW and randomly assigned within block to 1 of 5 dietary treatments differentiated by the number of days prior to slaughter that diets containing DDGS were replaced with corn- soybean meal- (**CSBM**) based diets. Pigs were switched from a DDGS-based diet to CSBM at 76, 42, 27, 15, or 0 d (no dietary switch) before harvest. All pigs were provided 40% DDGS prior to the test period (22 to 66 kg).

Pens of pigs were weighed and feed disappearance was measured on d 76, 42, 27, 15, and 0 prior to marketing to determine average daily gain (**ADG**), average daily feed intake (**ADFI**), and feed efficiency (**G:F)**. In the case of a pig removal due to illness or death, pen gates were adjusted to maintain the desired floor space allowance (0.70 m^2/pig).

Pigs were given *ad libitum* access to feed and water throughout the study. Diets were fed in 4 sequential phases from approximately 66 to 82, 82 to 104, 104 to 122, and 122 kg until the end of the study (Table 1). Diets with DDGS during the trial contained 35% from approximately 66 to 82 kg and 30% in the remaining dietary phases. Diets were formulated to meet or exceed NRC (2012) recommendations for the nutrient requirements. Diets contained 3.6, 3.2, 3.0, and 3.0 g standardized ileal digestible (**SID**) Lysine (**Lys**) per Mcal of net energy (**NE**) in phases 1 through 4, respectively, and required Lys:NE ratio was derived from the genetic supplier's prediction equation based on commercial experiments (Gonçalves et al., 2017). Net energy of DDGS was calculated using an assumed oil content (7.5%) based on an equation by

Nitikanchana et al. (2013). Proximate analysis was completed on DDGS samples during the time of the trial and resulted in 90.5% dry matter, 26.7% crude protein, 7.6% crude fiber, and 8.8% ether extract. All diets were fed in meal form and manufactured at a commercial feed mill (Blooming Prairie, MN). Diet samples were obtained and stored at −20 °C until analysis. Samples were analyzed (Ward Laboratories, Inc., Kearney, NE) for DM (method 935.29; AOAC International, 1990), CP (method 990.03; AOAC International, 1990), Ca (method 985.01; AOAC International, 1990), P (method 985.01; AOAC International, 1990), ADF and NDF (Van Soest et al., 1991), and ether extract (method 920.39; AOAC International, 1990).

According to typical farm procedures, the four heaviest pigs were removed from each pen 15 d prior to the final barn marketing event, weighed, tattooed, and transported to a USDA-inspected packing plant (Tyson Fresh Meats, Waterloo, IA) for carcass data collection. Similarly, for the final barn marketing, all pigs were weighed and tattooed with pen identification number and pigs were then processed for data collection. Carcass measurements collected included hot carcass weight (**HCW**), backfat, loin depth, and percentage lean. A proprietary equation specific to the packer was utilized to calculate percentage lean. Carcass yield was calculated by dividing average HCW for the pen by the average live BW for the pen collected at the farm. On the final marketing day, belly fat samples (anterior to the manubrium) were collected from two pigs per pen during processing prior to carcass chilling. These samples were analyzed via gas chromatography according to procedures by Cromwell et al. (2011) for fatty acid (**FA**) analysis to calculate an iodine value (**IV**) according to the NRC (2012) standard equation as a percent of ether extract and fatty acid.

Statistical Analysis

Data were analyzed as a randomized complete block design for one-way ANOVA using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC) with pen considered the experimental unit, BW as blocking factor, and treatment as fixed effect. For intermediate periods, one-way ANOVA was utilized to evaluate the response between pens that had been switched from DDGS to CSBM diets vs. those pens that remained on DDGS diets at that point in time. To evaluate the effect of time, linear and quadratic contrasts were applied for the overall growth data and carcass data to evaluate the effect of duration following dietary switch. These coefficients were generated using PROC IML to account for unevenly spaced d of dietary switch. Block was removed for FA and IV analysis as its variance component estimate converged to 0. Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$. For intermediate periods, treatment means were separated when the overall F-test resulted in $P < 0.05$.

RESULTS

Analyzed values for dry matter, crude protein, acid detergent fiber, NDF, ether extract, Ca, and P content of experimental diets (Table 2) were consistent with formulated estimates. In diets containing DDGS, ADF and NDF content was approximately two times the level analyzed in CSBM diets. These NDF levels are similar to other published values for diets containing 30% DDGS (Lerner et al., 2019).

Body weights on d 76, 42, 27, and 15 prior to market showed no evidence ($P > 0.192$) for treatment differences (Table 3). During the period following dietary switch from d 76 to 42 prior to market, two treatments were evaluated: either switched from DDGS at d 76 before market or not yet switched. Average daily gain and G:F improved ($P < 0.001$) for pigs switched from

DDGS (40% during the pretest period) to CSBM diets on d 76 prior to market, but there was no evidence ($P = 0.265$) that feed intake was different between treatments. The following period (d 42 to 27 before market) evaluated a dietary switch from DDGS to CSBM at 76 or 42 d before market vs. no dietary switch and resulted in no evidence for differences in ADG, ADFI, or G:F ($P > 0.337$). For d 27 to 15 before market, there was no evidence ($P > 0.053$) that ADG and G:F differed due to treatment. Pigs still consuming DDGS-based diets had decreased ($P < 0.05$) ADFI compared to those pigs switched from DDGS on either d 42 or d 27 before market, which were not different from each other ($P > 0.05$). Pigs that switched from DDGS diets on d 76 prior to market had intermediate feed intake to all treatments ($P > 0.05$). Finally, for d 15 before market to market (d 0), G:F did not show evidence for differences ($P = 0.304$). Pigs switched to CSBM on d 15 before market had increased ($P < 0.05$) ADG compared to pigs switched on d 76 before market or those not switched. Furthermore, pigs switched to CSBM on d 27 before market had increased ($P < 0.05$) ADG compared to those pigs not switched from DDGS diets. Average daily feed intake was decreased ($P < 0.05$) in pigs with no dietary switch compared to those switched on d 42, 27, or 15 before market, but not different ($P > 0.05$) from those switched initially on d 76 before market. Additionally, ADFI was decreased ($P < 0.05$) for pigs on the 76 d before market dietary switch treatment compared to those switched to CSBM on d 27 before market.

Overall growth performance was evaluated using linear and quadratic contrasts to determine the effect of time of dietary switch from DDGS to CSBM (Table 4). For the overall period (d 76 before market to 0), as time after dietary switch increased, ADG and final BW increased (linear, $P < 0.018$) and G:F improved (quadratic, $P = 0.022$) for pigs switched from diets containing DDGS to diets without DDGS. Average daily feed intake increased (quadratic,

$P = 0.030$) with increasing time following dietary switch to CSBM with the greatest ADFI observed in those pigs switched from DDGS 27 d before marketing. The response detected in final BW resulted in an increase (linear, $P = 0.009$) in HCW, with a marginally significant response for improved carcass yield (linear, $P = 0.094$) with increasing time after dietary switch. Loin depth and lean percentage did not demonstrate any evidence ($P > 0.132$) for treatment differences. Backfat was increased (linear, $P = 0.030$) with increasing time of CSBM feeding.

There was no statistical evidence ($P > 0.209$) that duration following switch from DDGS to CSBM impacted individual fatty acid (**FA**) concentrations (Table 5), with the exception of palmitoleic acid, which displayed a marginally significant reduction (linear, $P = 0.071$) with decreased time following dietary switch. Iodine value of belly fat was decreased (linear, $P < 0.034$) with increased time after switch to CSBM when calculated both as a percent of FA and a percent of ether extract.

DISCUSSION

Corn DDGS are a good source of amino acids, energy, and P in swine diets. It has been demonstrated that DDGS can be fed to growing and finishing pigs at 15% of the diet without impacting growth performance (Linneen et al., 2008) while others suggest that up to 30% may have no detrimental effects (DeDecker et al., 2005; Stein and Shurson, 2009). Further, Hilbrands et al. (2013) report that DDGS can be abruptly added or removed from the diets with no negative impacts on finishing growth performance. Though DDGS can be an economically attractive ingredient to include in swine diets, they contain increased NDF content, which can negatively impact nutrient digestibility and carcass yield (Stein et al., 2016; Soto et al., 2019). Additionally, the oil content in DDGS contains increased concentration of unsaturated fatty acids, making feeding DDGS to finishing pigs a fat quality concern (Whitney et al., 2006). Given the negative

effects of feeding DDGS on carcass yield and carcass fat IV, switching to a CSBM diet before slaughter might mitigate these undesirable responses.

The impact of removing DDGS from finishing diets on growth performance is variable within the literature. In Graham et al. (2014), switching from a diet containing 30% DDGS- and 17% wheat middlings to CSBM for 24 d increased ADG compared to no dietary switch, but feeding CSBM for the entire 73-d experiment further increased ADG and G:F compared to the DDGS and midds removal strategy. Gaines et al. (2007) did not observe differences in ADG or ADFI with 3- or 6-week DDGS removal periods compared to 70 d of continuous CSBM or 30% DDGS diets, yet feeding DDGS for 70 d reduced G:F compared to CSBM. On the other hand, Coble et al. (2018) reported minimal differences in performance when switching pigs from high to low NDF diets for 0 to 24 d, although continuous feeding of CSBM for 96 d compared to all DDGS removal strategies improved ADG, G:F, and final BW. Asmus et al. (2014) observed improved feed efficiency with increasing duration following the dietary switch from DDGS and wheat middlings to CSBM. The observed improvements in growth rate and feed efficiency are likely a function of increased NE content of CSBM diets. Pigs in the current experiment that were switched from DDGS at 76 d prior to market had increased ADG and G:F after being switched to a CSBM diet, which contained greater NE than the DDGS-based diets. Given that feed intake of this higher energy diet increased, growth rate was further improved following dietary switch. This response is further supported by Lerner et al. (2019), who switched from DDGS diets to CSBM diets balanced in NE and found no evidence for differences in growth performance using 28 or 35 d DDGS removal periods.

Increases in feed intake following dietary switch were observed for overall ADFI, as well as some intermediate periods in the current experiment. This is notable because pigs actually

increased consumption of a more energy-dense diet. Asmus et al. (2014) and Coble et al. (2018) observed a similar effect following switch from DDGS and wheat middlings and proposed that this response is related to gut fill capacity. When pigs are removed from high fiber diets, they may naturally continue to consume the same volume of feed, which is actually increased feed on a weight-basis due to the higher bulk density of the CSBM diet. It appears that this phenomenon can be regulated over time, which describes the quadratic response in the overall ADFI.

Fiber has been demonstrated to decrease carcass yield due to its ability to increase intestinal fill and intestinal weight (Turlington, 1984; Asmus et al., 2014). The efficacy of switching pigs from high NDF to lower NDF, CSBM diets prior to harvest to recover carcass yield is well documented, and many researchers utilized diets that contained both 30% DDGS and 19% wheat middlings to increase dietary NDF level (Asmus et al., 2014; Graham et al., 2014; Nemechek et al., 2015; Coble et al., 2018). Using this combination of DDGS and midds, Asmus et al. (2014) reported that carcass yield losses were recovered in d 23 following dietary switch to CSBM, while Coble et al. (2018) noted that carcass yield and HCW could be recovered in as little as 9 d. Conversely, others have reported that 17 to 24 d only provided partial carcass yield recovery (Graham et al., 2014; Nemechek et al., 2015), but carcass yield was still less than that of pigs consuming CSBM throughout the entire experiment (Nemechek et al., 2015). When feeding 30% DDGS alone (without midds), Gaines et al. (2007) observed that 42 d was enough time following dietary switch to CSBM to recover carcass yield. In the current experiment, HCW and carcass yield were both improved with increased time following fiber reduction. Though the duration of fiber reduction in the present experiment is longer than many of the aforementioned studies, the data agrees with most of the fiber reduction studies in that yield may begin to numerically recover in 27 d. However, due to the linear nature of the response in HCW and

carcass yield observed in this experiment, pigs needed at least 76 d of fiber reduction, which agrees with Nemechek et al. (2015). The need for a longer period following dietary switch than reported in Asmus et al. (2014) and Coble et al. (2018) may be dependent on other unknown factors such as pretrial feeding regimens, specifically the NDF content of diets prior to the beginning of the experiments. Pigs in the current experiment consumed 40% DDGS starting at 20 kg, possibly making a longer fiber reduction period necessary.

Soto et al. (2019) used meta-analysis to model the change in yield with increased days following dietary switch and various NDF levels. This model predicted a 1.0, 0.9, 0.7, and 0.6% increase in yield for the treatments switched at 76, 42, 27, or 15 d, respectively, prior to market. In the present data, yield was increased by 0.6, 0.6, 0.3, or 0% for the 4 dietary switch intervals. This model seems to be a useful tool to understand the impact of NDF on carcass yield, though the current data have a longer fiber reduction period than the studies included in the meta-analysis, which may cause some variation in the estimates.

Another response with economic implications is carcass fat IV, which many pork processors monitor and enforce discounts beyond a given threshold. Iodine value, which is an indication of the level of unsaturated fatty acids present in carcass fat deposits, is generally increased when DDGS are fed due to the unsaturated fatty acids found in corn oil (Stein and Shurson, 2009). Softer pork fat resulting from increased levels of unsaturation may cause undesirable pork quality (Widmer et al., 2008; Garnsworthy and Wiseman, 2009). Xu et al. (2010) suggest that removing DDGS from the diet for 3 weeks could lower carcass fat IV to levels of pigs not fed DDGS; however, other evidence suggest that this may take longer to recover. Jacela et al. (2009) reported that a 6-week period following dietary switch did not completely restore carcass fat IV when comparing feeding 30% DDGS to no DDGS. The present

study found that carcass fat IV continued to decrease up to the 76 d dietary switch, yet a numerical reduction was found even when removing DDGS for only 15 d, which is in agreement with other literature (Asmus et al., 2014; Coble et al., 2018).

In conclusion, switching from DDGS to CSBM diets starting at 76 d prior to market increased growth rate and feed efficiency, which resulted in an additional 5 kg of HCW. This response is primarily due to increased net energy content and reduced fiber level of diets without DDGS. Iodine value was decreased with increased time following DDGS removal, yet improvement was seen with removal periods as short as 15 d. Therefore, strategies that switch from DDGS to CSBM-based diets may be useful when DDGS are added to swine diets to reduce the negative effect of decreased growth performance, reduced carcass weights and yield, and decreased fat saturation. Feeding DDGS for extended periods during the finishing period may result in poorer pig performance compared to CSBM if the difference in NE is not accounted for.

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Table 2-1. Diet composition, phases 1 through 4

	Dietary phase							
	DDGS[1]				Corn soybean meal			
Ingredient, %	1[2]	2	3	4	1	2	3	4
Corn	55.49	60.74	60.52	62.00	78.65	81.60	82.77	82.76
Soybean meal, 46.5% crude protein	6.58	6.52	6.92	5.55	18.26	15.47	14.37	14.62
Corn DDGS	35.00	30.00	30.00	30.00	---	---	---	---
Monocalcium phosphate, 21% phosphorus	0.10	0.10	0.09	---	0.78	0.70	0.65	0.50
Limestone	1.20	1.20	1.15	1.05	0.85	0.88	0.90	0.78
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Copper sulfate	0.03	---	---	---	0.03	---	---	---
L -Lysine HCl	0.55	0.45	0.40	0.45	0.34	0.30	0.30	0.30
DL-Methionine	---	---	---	---	0.05	0.04	0.04	0.05
L-Threonine	0.07	0.05	0.04	0.08	0.08	0.08	0.10	0.12
L-Tryptophan	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03
Premix[4]	0.20	0.15	0.10	0.10	0.20	0.15	0.10	0.10
Phytase[5]	0.10	0.10	0.10	0.08	0.10	0.10	0.10	0.10
Sodium metabisulfite	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100	100	100
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lysine:net energy, g/Mcal	3.56	3.15	3.04	3.04	3.56	3.15	3.04	3.06
Lysine	0.88	0.78	0.76	0.76	0.89	0.79	0.77	0.77
Isoleucine:lysine	60	64	67	64	59	61	60	61
Leucine:lysine	183	194	203	197	139	148	150	149
Methionine:lysine	32	34	36	35	31	32	32	34
Methionine + cysteine:lysine	60	64	67	65	56	59	60	61

Threonine:lysine	60.7	63.0	64.9	67.2	60.4	62.9	65.1	67.6
Tryptophan:lysine	17.8	19.3	19.7	19.2	19.3	20.3	19.6	19.7
Valine:lysine	75	80	84	80	67	70	70	70
Total lysine, %	1.05	0.94	0.91	0.91	1.00	0.90	0.87	0.88
Net energy, kcal/kg	2,469	2,487	2,487	2,502	2,500	2,520	2,526	2,533
CP, %	17.8	16.7	16.9	16.4	15.4	14.3	13.9	14.0
Ca, %	0.54	0.53	0.51	0.45	0.54	0.53	0.53	0.45
P, %	0.42	0.40	0.40	0.38	0.49	0.47	0.45	0.42
Available P, %	0.35	0.33	0.32	0.29	0.35	0.34	0.32	0.29
Analyzed composition, %[6]								
Dry matter	88.7	88.5	88.4	88.9	87.5	88.2	87.4	87.3
Crude protein	16.0	16.1	16.6	16.8	14.8	12.8	12.5	12.6
Acid detergent fiber	6.5	6.7	6.2	5.4	3.0	2.9	3.1	3.5
Neutral detergent fiber	12.9	12.1	12.6	12.0	5.7	6.3	6.5	6.1
Calcium	0.74	0.65	0.69	0.63	0.71	0.93	0.69	0.65
Phosphorus	0.59	0.50	0.54	0.51	0.51	0.45	0.46	0.40
Ether extract	4.80	4.30	4.20	4.40	2.70	2.70	3.00	2.90

[1] DDGS = corn distillers dried grains with solubles.

[2] Diets were fed in four sequential phases from approximately 66 to 82, 82 to 104, 104 to 122, and 122 until 131 kg.

[4]Provided 1,543,220 IU vitamin A from vitamin A acetate; 440,920 IU vitamin D from vitamin D_3; 8,047 IU vitamin E from dl-α-tocophorol acetate; 882 mg menadione from menadione nicotinamide bisulfite; 8 mg B_{12} from cyanocobalamin; 14,991 mg niacin from niacinamide; 6,614 pantothenic acid from d-calcium panthothenate; 1,984 mg riboflavin from crystalline riboflavin; 3 g Cu from copper sulfate; 160 mg Ca from calcium iodate; 31 mg Fe from ferrous sulfate; 3 g Mn from manganese sulfate; 120 mg Se from sodium selenite; and 31 g Zn from zinc sulfate per kg of premix.

[5]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) provided 1,102,300 phytase units/kg of product with an assumed release of 0.14% and 0.12% available P for 0.1% and 0.8% inclusion levels, respectively.

[6] Samples were analyzed at Ward Laboratories (Kearney, NE).

Table 2-2. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on growth performance[1,2]

	DDGS diet removal before market, d					
Item[3]	76	42	27	15	0	Probability, *P* =
BW, kg						
d -76	66.1	---	---	---	66.2	0.906
	2.00	---	---	---	1.77	
d -42	102.1	100.0	---	---	99.9	0.278
	2.26	2.26	---	---	2.04	
d -27	113.5	110.6	111.0	---	110.7	0.192
	2.29	2.29	2.29	---	1.16	
d -15	121.4	119.9	119.9	118.3	118.5	0.451
	2.30	2.30	2.30	2.30	2.30	
d -76 to -42						
n (pens):	7	---	---	---	28	
ADG, kg	1.06[a]	---	---	---	0.98[b]	0.001
	0.023	---	---	---	0.020	
ADFI, kg	2.71	---	---	---	2.67	0.265
	0.092	---	---	---	0.087	
G:F	0.392[b]	---	---	---	0.370[a]	0.001
	0.0066	---	---	---	0.0058	
d -42 to -27						
n (pens):	7	7	---	---	21	
ADG, kg	0.75	0.71	---	---	0.72	0.565
	0.033	0.033	---	---	0.020	
ADFI, kg	2.60	2.59	---	---	2.67	0.374
	0.12	0.12	---	---	0.109	
G:F	0.293	0.277	---	---	0.271	0.379
	0.0148	0.0148	---	---	0.0096	
d -27 to -15						
n (pens):	7	7	7	---	14	
ADG, kg	0.70	0.76	0.71	---	0.63	0.053
	0.042	0.042	0.042	---	0.033	
ADFI, kg	2.63[a,b]	2.78[a]	2.74[a]	---	2.43[b]	0.004
	0.084	0.084	0.084	---	0.063	
G:F	0.265	0.276	0.261	---	0.259	0.773
	0.0149	0.0149	0.0149	---	0.0115	
d -15 to 0						
n (pens):	7	7	7	7	7	
ADG, kg	0.94[b,c]	0.97[a,b,c]	1.00[a,b]	1.03[a]	0.89[c]	0.018
	0.028	0.028	0.028	0.028	0.028	
ADFI, kg	3.24[b,c]	3.33[a,b]	3.44[a]	3.37[a,b]	3.11[c]	0.002
	0.067	0.067	0.067	0.067	0.067	
G:F	0.291	0.291	0.290	0.306	0.287	0.291
	0.0089	0.0089	0.0089	0.0089	0.0089	

[abc]Means lacking common superscripts differ ($P < 0.05$).

[1]A total of 860 finishing pigs (initially 66.1 ± 5.03 kg) were used in a 76-d experiment to evaluate the effects of removing corn dried distillers grains with solubles (DDGS) from diets at increasing intervals prior to harvest.

[2]All pigs were fed diets containing 40% DDGS until the start of the trial. Diets with DDGS during the trial contained 35% from approximately 66 to 82 kg and 30% until the completion of the trial.

[3] Standard error of the means are reported below the treatment means.

Table 2-3. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market overall growth performance and carcass characteristics finishing pigs[1,2,3]

	DDGS diet removal before market, d						Probability, *P* =	
Item	76	42	27	15	0	SEM	Linear	Quadratic
Growth performance								
d -76 to 0								
ADG, kg	0.92	0.88	0.89	0.88	0.86	0.012	0.002	0.973
ADFI, kg	2.78	2.80	2.85	2.77	2.73	0.071	0.251	0.030
G:F	0.330	0.315	0.315	0.320	0.316	0.0063	0.003	0.019
Final BW, kg	133.8	131.7	132.0	130.6	128.6	2.22	0.018	0.573
Carcass characteristics								
HCW, kg	99.1	97.7	97.2	96.1	94.8	1.82	0.010	0.554
Carcass yield, %	73.6	73.6	73.3	73.0	73.0	4.13	0.094	0.615
Loin depth, mm^3	71.8	72.0	71.8	72.4	72.7	0.71	0.335	0.532
Backfat, mm^3	13.1	12.7	13.2	12.7	12.1	0.68	0.030	0.084
Lean, %[3]	57.1	57.2	57.1	57.3	57.4	0.20	0.132	0.232

[1]A total of 860 finishing pigs (initially 66.1 ± 5.03 kg) were used in a 76-d experiment to evaluate the effects of removing corn DDGS from diets at varying intervals prior to harvest.

[2]Pigs were fed diets containing 40% DDGS until the start of the trial. Diets with DDGS during the trial contained 35% from approximately 66 to 82 kg and 30% until the completion of the trial.

[3] Hot carcass weight (HCW) was used as a covariate for loin depth, backfat, and percent lean.

Table 2-4. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on fatty acid analysis of belly fat samples[1,2]

	DDGS diet removal before market, d						Probability, *P* =	
Item,%[4]	76	42	27	15	0	SEM	Linear	Quadratic
Myristic acid (C14:0), %	1.93	2.06	1.70	1.87	1.74	0.142	0.261	0.586
Palmitic acid (C16:0), %	29.13	29.81	27.56	29.72	25.77	1.945	0.329	0.385
Palmitoleic acid (C16:1), %	3.87	4.12	3.17	3.76	3.13	0.291	0.071	0.382
Stearic acid (C18:0), %	7.86	7.03	9.28	7.85	9.25	1.237	0.411	0.605
Oleic acid (C18:1 *cis*-9), %	37.25	35.70	37.44	34.85	38.27	2.736	0.959	0.571
Linoleic acid (C18:2n-6), %	15.07	16.33	16.63	16.71	17.61	1.508	0.243	0.995
Arachidic acid+ gamma-linolenic acid (C20:0+C18:3n-6), %	0.33	0.37	0.29	0.33	0.28	0.033	0.243	0.349
α-Linolenic acid (C18:3n-3), %	0.72	0.73	0.63	0.69	0.60	0.070	0.209	0.640
Gadoleic acid (C20:1), %	0.65	0.78	0.67	0.70	0.80	0.075	0.292	0.982
Dihomo-gamma-linolenic (C20:3n-6), %	0.09	0.12	0.07	0.09	0.15	0.028	0.387	0.429
Arachidonic acid (C20:4n-6), %	0.36	0.37	0.37	0.39	0.35	0.036	0.918	0.680
Other FA, %	2.70	2.58	2.12	2.68	2.03	0.362	0.275	0.827
Iodine value, % of EE[3]	68.1	69.5	70.0	68.7	72.6	1.13	0.031	0.365
Iodine value, % of FA[4]	65.2	66.5	67.0	65.8	69.4	1.08	0.030	0.364

[1]A total of 860 finishing pigs (initially 66.1 ± 5.03 kg) were used in a 76-d experiment to evaluate the effects of removing corn DDGS from diets at varying intervals prior to harvest. Belly fat samples were collected from 2 pigs/pen to perform fatty acid (FA) analysis via gas chromatography.

[2] Pigs were fed diets containing 40% DDGS until the start of the trial. Diets with DDGS during the trial contained 35% from approximately 66 to 82 kg and 30% until the completion of the trial.

[3] Fatty acid (FA) concentrations were obtained via gas chromatography. Iodine value was calculated according to the NRC (2012) equation and consider FA as a percent of ether extract (EE): Iodine value = [% C16:1] × 0.9976 + [% C18:1] × 0.8985 + [% C18:2] × 1.8099 + [% C18:3] × 2.7345 + [% C20:1] × 0.8173 + [% C22:1] × 0.7496 + [% C22:5] × 3.8395 + [% C22:6] × 4.6358.

[4] Fatty acid (FA) values obtained via gas chromatography (GC). Iodine value was calculated according to the NRC (2012) equation and consider FA as a percent of total FA: Iodine value = [% C16:1] × 0.9502 + [% C18:1] × 0.8598 + [% C18:2] × 1.7315 + [% C18:3] × 2.6152 + [% C20:1] × 0.7852 + [% C22:1] × 0.7225 + [% C22:5] × 3.6974 + [% C22:6] × 4.4632.

Chapter 3 - Effects of corn distillers dried grains with solubles in finishing diets on growth performance and carcass yield with two different marketing strategies

ABSTRACT

Feeding diets high in corn distillers dried grains with solubles (**DDGS**) before market can negatively impact carcass yield, hot carcass weight (**HCW**), and belly fat iodine value (**IV**). Two experiments were conducted to evaluate the effects of switching from DDGS-based to corn-soybean meal (**CSBM**)- based diets at increasing intervals before harvest on finishing pig performance and carcass characteristics. Diets in both experiments contained either 0 or 30% DDGS and were balanced for net energy (**NE**). In Exp. 1, 985 pigs (initially 99.6 kg body weight [**BW**]) were used with 12 pens per treatment. The four treatments were increasing in duration of time after pigs were switched from diets containing DDGS to CSBM diets before marketing: 28, 21, 14, or 0 d (no dietary switch). All pens were marketed by removing the 17% heaviest pigs 21 d before slaughter and the remaining 83% all slaughtered 21 d later. Overall, there was no evidence for treatment differences on final BW, average daily feed intake (**ADFI**), or feed efficiency (**G:F;** $P > 0.10$); however, average daily gain (**ADG**) increased (linear, $P = 0.022$) and belly fat IV decreased (linear, $P = 0.001$) the longer pigs were fed CSBM diets. There was no evidence for differences for HCW ($P > 0.10$); however, carcass yield increased (linear, $P = 0.001$) with increasing time following the switch to CSBM. Backfat depth decreased and percentage lean increased as CSBM feeding time increased (quadratic; $P < 0.05$). In Exp. 2, 1,158 pigs (initially 105 kg BW) were used in a 35-d study. There were 15 pens per treatment and four treatments increasing in time after pigs were switched from diets containing DDGS to

CSBM diets before marketing: 35, 28, 14, or 0 d (no dietary switch). All pens were marketed by removing the 15% heaviest pigs on d 28, the 28% heaviest pigs on d 14, and a final marketing of approximately 57% of starting barn inventory. There was no evidence that final BW, ADG, G:F, or HCW differed among dietary treatments ($P > 0.10$). Average daily feed intake and carcass yield increased and belly fat IV decreased ($P < 0.050$) the longer pigs were fed CSBM. In conclusion, growth performance was minimally impacted following dietary switch from DDGS to CSBM, likely due to similar dietary NE. For carcass yield and belly fat IV, the optimal time to make a dietary switch from high to low fiber appears to be linear in nature and at least 28 days before marketing.

INTRODUCTION

Corn distillers dried grains with solubles (DDGS) is a byproduct of the ethanol industry. Information regarding use of DDGS in growing-finishing diets is widely available, and generally concludes that DDGS may be included in diets at up to 30% before adverse effects in growth performance are observed (Stein and Shurson, 2009); however, a majority of this data was collected prior to 2009, where oil content was higher than that of current DDGS. DDGS are high in neutral detergent fiber (**NDF**), and thus may negatively affect carcass yield and hot carcass weights (Coble et al., 2017). Additionally, DDGS contain relatively high concentrations of unsaturated fatty acids which can lead to increased pork fat iodine value (Whitney et al., 2006). Decreased carcass yield and poor fat quality can result in economic ramifications when marketing pigs.

To overcome the negative effects of feeding DDGS (or high NDF diets) before market, pigs may be switched from diets containing high NDF to corn-soybean meal diets in the final days or weeks of the finishing period. Coble et al. (2017) reported that a 5 or 9 d withdrawal

(time of dietary switch from DDGS- to corn-soybean meal-based diets) of DDGS and wheat middlings recovered yield and HCW reductions. Asmus et al. (2014) fed finishing pigs diets containing both DDGS and wheat middlings and changed the NDF levels in finishing diets either 43 or 67 d before slaughter, concluding that short CSBM feeding durations could recover yield losses, but longer periods were needed to restore carcass fat IV.

Often in commercial pork production, groups of pigs that reach market weight requirements ahead of their cohorts are sold prior to the final barn marketing, rather than selling all pens of pigs at one time. Strategies that utilize multiple marketing events are effective in reducing market weight variation and improving the growth performance of the remaining pigs (Woodworth et al., 2000; DeDecker et al., 2005; Dedecker, 2006). Due to seasonal changes in pig growth, pork prices, and space availability within a production system, multiple marketing strategies may be utilized differently throughout the year to maximize profitability. For example, increased temperatures can result in poor feed intake, feed conversion, and growth rate (White et al., 2008). Therefore, pigs often grow slower during the summer than winter. To account for these seasonal differences in growth rates, many swine producers utilize more marketing events during cool months as pigs reach market weight faster than during warm months.

Therefore, it is important to understand the appropriate feeding duration of DDGS before harvest in order to maximize profitability while mitigating reductions in performance, carcass yield, and pork quality. The objective of these experiments was to determine the appropriate time to switch from diets containing DDGS to those containing only corn and soybean meal before marketing in finishing pig diets in two different marketing scenarios.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. Both studies were conducted at a commercial research facility owned and operated by New Fashion Pork (Jackson, MN). The barns were tunnel-ventilated with completely slatted concrete flooring and deep pits for manure storage. Each pen (2.4 × 5.8 m, Exp. 1; 2.4 × 5.5 m, Exp. 2) was equipped with adjustable gates and a 3-hole, dry feeder (Thorp Equipment, Inc., Thorp, WI) and a pan waterer. Feed and water were offered ad libitum and feed additions were delivered and recorded using a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN). In each trial, two different marketing strategies were employed representative of marketing techniques used in warm and cold months. The first experiment had one marketing event then sold all pigs 21 d later, and the second experiment had two marketing events before the remaining pigs were sold.

Experiment 1

For Exp. 1, 985 finishing pigs (initially 100 ± 2.5 kg BW; PIC TR4 × (Fast LW × PIC L02) were used in a 28-d experiment. Pen served as the experimental unit with 12 pens per treatment and 19 to 21 pigs per pen. There were four treatments increasing in duration after diets containing DDGS were switched for corn-soybean meal- based (**CSBM**) diets before final marketing: 28, 21, 14, or 0 d (no dietary switch). Regardless of treatment, pens of pigs were marketed with one marketing event prior to final barn marketing (d 0), which mimics a seasonal marketing structure commonly implemented during warm months when pigs are growing slower. All pens were marketed by removing the 17% heaviest pigs on d 21 prior to market resulting in a final barn marketing of approximately 83% of starting pen inventory. Pens of pigs were weighed

every 7 d, with individual weights collected at marketing. Growth performance includes pigs sold prior to final marketing events.

Pigs were provided ad libitum access to feed and water. Prior to the experiment, all pigs were fed diets containing 30% DDGS starting at 34 kg BW. Diets were either CSBM-based or contained 30% DDGS (Table 1). All diets were formulated to meet or exceed NRC (2012) nutrient requirement estimates. Experimental diets contained 0.77% standardized ileal digestible (**SID**) lysine and were balanced for net energy (**NE**). Nutrient values for all ingredients and standardized ileal digestibility coefficients of amino acids used in diet formulation were derived from NRC (2012). Net energy of DDGS was calculated using an assumed oil content (7.5%) based on an equation by Nitikanchana et al. (2013). Proximate analysis completed on DDGS samples taken during the experiment resulted in 88.5% dry matter, 27.7% crude protein, 5.8% crude fiber, and 6.8% ether extract. Feed was manufactured at a commercial mill (Worthington, MN). Composite diet samples were obtained and stored at −20 °C until analysis. Samples were analyzed (Ward Laboratories, Inc., Kearney, NE) for DM (method 935.29; AOAC International, 1990), CP (method 990.03; AOAC International, 1990), Ca (method 985.01; AOAC International, 1990), P (method 985.01; AOAC International, 1990), ADF and NDF (Van Soest et al., 1991), and ether extract (method 920.39; AOAC International, 1990).

Pigs to be harvested were identified with tattoos indicating pen of origin and RFID ear tags for individual identification. Pigs were then transported to a USDA-inspected packing plant (Triumph Foods, St. Joseph, MO) for processing and carcass data collection. Carcass measurements collected on pigs from all marketing events included HCW, backfat, loin depth, and lean percentage. Carcass yield was calculated by dividing the individual pig's live weight at the farm by the individual pig's HCW. A proprietary equation specific to the packer was utilized

to calculate percentage lean. On the final barn marketing days, belly fat samples anterior to the manubrium were collected from 4 barrows per pen. Samples were analyzed by near infrared spectroscopy (Triumph, St. Joseph, MO) for fat IV using the equation by Cocciardi et al. (2009).

Experiment 2

In Exp. 2, 1,158 finishing pigs (initially 105 ± 2.0 kg BW) were used in a 35-d experiment. Pen served as the experimental unit, with 15 pens per treatment and 17 to 21 pigs per pen. Adjustable gating provided all pens with 0.71 m^2/pig. Similar to Exp. 1, there were four treatments increasing in duration after diets containing DDGS were switched for CSBM diets before final marketing: 35, 28, 14, or 0 d (no dietary switch). All pens were marketed according to a typical winter marketing strategy for this production system with two marketing events prior to the final barn marketing. During the winter months pigs generally grow faster than summer months, thus reaching the ideal market weight faster. Hence, pigs are generally marketed in multiple marketing events during the winter. All pens were marketed by removing the 15% heaviest pigs on d 28 prior to market, the next 28% heaviest pigs on d 14 prior to market, and a final barn marketing of approximately 57% of starting barn inventory. Pigs were weighed every 7 d. Experimental diets and carcass collection procedures were identical to Exp. 1.

Statistical Analysis

Data were analyzed as a completely randomized design with the fixed effects of treatment using the PROC GLIMMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC). Pen was the experimental unit for growth and carcass data. To evaluate growth data, each intermediate period was analyzed with an individual ANOVA model to evaluate the fixed effect of treatment at that point in time. For example, during d 28 to 21 before marketing in Exp. 1, the only treatment to be applied was the 28-d dietary switch; therefore, these pens are compared to

the remaining pens that were yet to be assigned to treatment and switched to CSBM diets. Individual carcass data were analyzed with a mixed model using PROC GLIMMIX to account for the correlation among pigs sharing the same pen (EU) with a repeated measures design. To evaluate the effect of time, linear and quadratic contrasts were applied for the overall growth and carcass data to evaluate the effect of duration following dietary switch from DDGS to CSBM across all treatments. The PROC IML procedure was utilized to generate linear and quadratic coefficients for unevenly spaced time between dietary switches. In Exp. 1, one pen was removed from the data set due to incorrect feed provided to the pen during the final period. Residual outliers within the carcass data were removed if plant data provided evidence indicating a defect where the carcass was skinned. In addition, two carcasses in Exp. 2 were removed because their residual values were notably increased compared to the overall population. No carcasses were removed for Exp 1. Results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

RESULTS

Analyzed diet composition was similar to anticipated values for all proximate analysis components (Table 2). Further, DDGS diets contained increased NDF content compared to CSBM diets as expected. Levels of NDF were similar to other literature (12 to 13%) when diets included 30% DDGS (Lerner et al., 2019), yet lower than experiments that included both 30% DDGS and 19% wheat middlings (Asmus et al., 2014; Coble et al., 2018).

Experiment 1

There was no evidence ($P > 0.10$) for treatment differences in BW throughout the trial (Table 3). During d 28 to 21 before final barn marketing, there was no evidence ($P > 0.10$) for treatment differences in average daily gain (**ADG**), average daily feed intake (**ADFI)**, or feed

efficiency (**G:F**). The following period, d 21 to 14 before market, evaluated three treatments: switching to CSBM on either d 28 before market, d 21 before market, or not yet switched. There was no evidence ($P = 0.364$) that ADFI was different between treatments. Average daily gain was increased ($P < 0.05$) for pigs switched to CSBM diets compared to pens of pigs remaining on diets containing DDGS. Feed efficiency was improved ($P < 0.05$) for pigs switched to CSBM diets 21 d before marketing compared to pigs with no dietary switch, while pigs switched on d 28 before market had intermediate G:F ($P > 0.05$). During d 14 to 7 before market, ADG did not result in evidence for differences across treatments ($P > 0.10$). Feed intake was increased ($P < 0.05$) for pens switched to CSBM on d 28 or 21 before market compared to pens that remained on DDGS, yet ADFI was not different from each other ($P > 0.05$). Pens of pigs switched on d 14 before market had intermediate ($P > 0.05$) ADFI compared to the other treatments. Feed efficiency was not different ($P > 0.05$) between the d 14 dietary switch and no dietary switch treatments, but their G:F was improved ($P < 0.05$) compared to the 21-d dietary switch treatment. Pens switched from DDGS to CSBM on 28 d before market had intermediate G:F ($P > 0.05$) compared with all other treatments. There was no evidence ($P > 0.10$) that ADG, ADFI, or G:F differed for the last 7 d of the trial.

For the first marketing event on 21 d before market (Table 4), there was no evidence ($P > 0.10$) for treatment differences in HCW, backfat, loin depth, or lean percentage. Carcass yield tended ($P = 0.089$) to be increased for pigs switched from DDGS to CSBM on d 28 before market (or 7 d before the first marketing event) compared to those still consuming DDGS. The remaining pigs were marketed at the end of the trial (d 0), representing the final barn marketing in which all treatments were evaluated. For this final marketing event, there was a marginally significant (linear, $P = 0.061$) response where HCW increased with increasing time after dietary

switch from DDGS to CSBM. Furthermore, carcass yield was increased (linear, $P = 0.001$) as time of dietary switch before market increased. Backfat tended to increase (quadratic, $P = 0.073$) with increased time after dietary switch. Loin depth and percentage lean tended to increase (linear, $P < 0.084$) with increasing duration before market after dietary switch. Lastly, belly fat IV decreased (linear, $P = 0.001$) with increased time after switching from DDGS to CSBM. For overall data, there was no evidence ($P > 0.112$) for dietary treatment effects on final BW, ADFI, or G:F (Table 5). However, ADG increased (linear, $P = 0.022$) as time after switching from DDGS to CSBM increased before marketing. There was no evidence ($P > 0.106$) for treatment differences in HCW or loin depth. Carcass yield was increased (linear, $P < 0.001$) with increasing time after dietary switch from DDGS to CSBM. Backfat decreased (quadratic; $P = 0.019$) and percentage lean increased (quadratic; $P = 0.033$) as time after dietary switch from DDGS to CSBM increased.

Experiment 2

There was no evidence that initial or subsequent BW were different ($P > 0.535$) between treatments (Table 6). During d 35 to 28 prior to market, pigs switched from DDGS-based to CSBM diets on d 35 prior to market had increased ($P = 0.007$) feed intake and tended ($P = 0.066$) to have increased ADG compared to pigs still consuming DDGS. There was no evidence ($P = 0.873$) for treatment differences in G:F during this period. From d 28 to 21 before market, there was no evidence ($P > 0.135$) for differences across treatments for ADG or ADFI. Pigs switched from DDGS to CSBM on d 35 before market had poorer ($P < 0.05$) G:F compared to pigs either switched on d 28 prior to market or not yet switched, which were not different from each other ($P > 0.05$). The subsequent period (d 21 to 14 before market) evaluated the same three treatments and resulted in no evidence for treatment differences for G:F ($P = 0.317$). Average

daily gain was similar ($P > 0.05$) between the treatments that were switched from DDGS to CSBM on either d 35 or d 28 before market, and both treatments had increased ($P < 0.05$) ADG compared to pens remaining on the DDGS diet. Feed intake during d 21 to 14 before marketing increased ($P < 0.05$) for pens of pigs switched from DDGS on d 28 before market compared to those still consuming DDGS diets, with the pigs removed from DDGS for 35 d having intermediate ADFI ($P > 0.05$). All four treatments were evaluated during d 14 to 7 before market. There was no evidence ($P > 0.05$) for treatment differences in ADG or G:F. Average daily feed intake was decreased ($P < 0.05$) for the treatment remaining on DDGS diets compared to all other treatments, which were not different ($P > 0.05$) from each other. During d 7 to 0 before market, ADG and ADFI had marginally significant differences across treatments ($P < 0.086$). Pigs switched from DDGS to CSBM on d 35, 14, or not at all had increased ($P < 0.05$) ADG compared to those switched on d 28 before market. Feed intake was increased for pigs switched to CSBM on d 35 or 14 before market compared to those not yet switched ($P < 0.05$). Feed efficiency was poorer ($P < 0.05$) for pigs removed from DDGS at 28 d before market compared to all other treatments, which were similar ($P > 0.05$) to each other.

Both marketing events before the final barn marketing resulted in no evidence for treatment differences in any carcass response criteria ($P > 0.132$, Table 7), with the exception of HCW at the second marketing (d 14 before market), which tended ($P = 0.067$) to be greater for pigs switched to CSBM on d 35 prior to market compared to those not yet switched. For the final marketing event at the end of the study (d 0), no evidence ($P > 0.224$) for treatment differences were observed for HCW, backfat, loin depth, or percentage lean. Carcass yield increased and belly fat IV decreased (linear, $P < 0.022$) as time after dietary switch from DDGS to CSBM increased before marketing.

There was no evidence that final BW, overall ADG, or overall G:F differed across treatments ($P > 0.116$; Table 8); however, ADFI increased (linear, $P = 0.015$) as time consuming CSBM increased. For the overall carcass data, HCW, backfat, loin depth, and percentage lean were not different based on treatment ($P > 0.05$). Carcass yield increased (linear; $P = 0.034$) with increasing time after switch from DDGS to CSBM diets.

DISCUSSION

Literature has demonstrated that DDGS and other high NDF ingredients can decrease carcass yield due to increased gut fill and intestinal weights (Turlington, 1984; Linneen et al., 2008; Asmus et al., 2014). Further, pork fat quality may be negatively impacted as a result of the increased unsaturated fatty acid content of DDGS, which can lead to increased IV (Benz et al., 2008; Graham et al., 2014; Nemechek et al., 2015). To avoid the economic ramifications that result from decreased carcass yield and fat quality, pigs can be switched from diets containing DDGS to CSBM diets before harvest. However, the suggested time of this dietary switch varies within the literature. Some studies suggest 5 to 10 d (Asmus et al., 2014; Coble et al., 2018), while Gaines et al. (2007b) found that six weeks was necessary to completely recover carcass yield losses. However, it is generally understood that fat quality takes longer to recover than carcass yield following dietary switch from DDGS to CSBM (Asmus et al., 2014) .

In our experiments, switching from DDGS to CSBM resulted in a relatively small response, increasing ADG by approximately 0.05 kg (Exp. 1) and ADFI by 0.1 kg (Exp. 2) with neither of these resulted in increased final BW or HCW. We hypothesize that the smaller response in these experiments compared with others is because diets were balanced for NE content. When pigs are switched from a low energy, higher fiber diet to a higher energy, lower fiber diet, they tend to eat similar volumes resulting in greater feed intake on a weight basis.

Therefore, when pigs were switched from DDGS to corn-SBM-based diets that contained similar NE levels, there were negligible responses in rate of gain or feed efficiency. Because diets did not differ in energy, pigs did not adjust feed intake as would be expected when dietary energy is manipulated. To the best of our knowledge, these are the first trials conducted with DDGS removal prior to marketing that balanced both the DDGS and CSBM diets for NE.

A more commonly used approach to feeding DDGS involves allowing NE content to change between the DDGS and CSBM diets. In these cases where diets are not balanced for NE, finishing performance may improve after DDGS are removed from diets due to the increased NE available in the CSBM diets. Asmus et al. (2014) did not balance for NE and observed that removing DDGS and wheat middlings from finishing pig diets improved G:F. Lerner et al. (2019) switched from DDGS to CSBM diets 76 d prior to market and reported linear increases in ADG and G:F with increasing time following dietary switch when diets were not balanced. In an experiment by Graham et al. (2014), pigs were switched from diets containing 30% DDGS and 19% wheat middlings to CSBM 24 d prior to market. During the last 24 d, pigs who were switched to the lower NDF/high NE diet had increased ADG and G:F compared to those who continued to consume the high NDF/low NE diet (Graham et al., 2014). Nemechek et al. (2015) also allowed NE level to change in low and high NDF diets and observed increased G:F with the fiber removal. These experiments demonstrate how a dietary switch from lower to higher energy diets may increase the growth rate and feed efficiency of finishing pigs. Thus, it is important to utilize the NE system in diet formulation when using high fiber ingredients to account for the impact of fiber on nutrient digestibility and potential ramifications on growth performance.

Carcass yield can be impacted by DDGS due to the ability of fiber to increase the weight and contents of the intestinal tract (Turlington, 1984; Asmus et al., 2014). The observed carcass

yield response in the present experiment is largely consistent with other experiments that fed DDGS prior to market. Coble et al. (2017) fed 0 or 30% DDGS for 20 d prior to market and observed no final BW effects, but feeding DDGS decreased HCW and yield. This response is consistent with much of the literature evaluating removing DDGS before harvest (Gaines et al., 2007a; Nemechek et al., 2015). Though the impact of feeding DDGS on carcass yield is well understood, the suggested time to remove DDGS from the diets to restore yield varies. Nemechek et al. (2015) reported that switching from high NDF to low NDF diets for 17-d improved carcass yield compared to no dietary switch, but was still decreased compared to a lower NDF control regimen fed for longer than 17 d. Coble et al. (2018) and Asmus et al. (2014) estimated that 5 to 10 d periods following dietary switch could recover yield, but Gaines et al. (2007b) reported that 42 d was necessary to fully recover yield. Our data suggests that the complete recovery period for yield is at least 35 d, but due to the linear nature of the response, the appropriate withdrawal time for full recovery may be longer. However, partial recovery can be observed in as little as 14 d.

Soto et al. (2019) developed a regression model to predict carcass yield based on NDF level in the diets immediately before harvest. This equation predicted a 1.0, 1.0, and 0.9% increase in carcass yield for Exp. 1 for durations of CSBM feeding of 28, 21, and 14 d, respectively. The actual carcass yield increased by 1.1, 0.8, and 0.9%. Experiment 2 had predicted increases in carcass yield of 1.2, 1.1, and 1.0 with a 35, 28, and 14 d duration after dietary switch to CSBM, respectively. The actual increases were more variable at 0.5, 0.4, and 0.2%. The equation of Soto et al. (2017) appears to be a useful tool to determine expected carcass yield with varying dietary NDF levels and dietary changes; however, the reason that

yield was not as greatly affected in the second experiment as in the first experiment remains unknown.

Regardless of dietary energy content, feeding DDGS consistently results in poorer fat quality, which can be measured by carcass fat IV. Increased IV indicates increased levels of unsaturated fatty acids. In both Exp. 1 and 2, IV increased by approximately 2 to 3 units, which could become meaningful if pigs are marketed to processing facilities that have quality control standards for carcass fat IV. Nevertheless, this response in belly fat IV is consistent with other literature where increased duration of DDGS removal prior to harvest decreased IV (Benz et al., 2008; Asmus et al., 2014; Nemechek et al., 2015).

The outcomes of both experiments were largely similar, regardless of marketing strategy. Carcass yield and belly fatty acid composition were negatively impacted, but this was driven by the pigs in the last market load that had been consuming their respective diets for the longest duration. Thus, in these experiments, the impact of switching from DDGS to CSBM appeared to be similar across two different seasonal marketing strategies. Nevertheless, further information regarding ingredient and carcass prices could influence the optimal timing of dietary fiber reduction and marketing strategy for maximizing profitability.

In summary, switching from DDGS diets to CSBM diets that were balanced for net energy had negligible effects on growth performance, regardless of whether one or two marketing events were implemented during the marketing period. However, in both studies, yield was increased and IV was decreased up to the 35 or 28 d CSBM feeding regimens. Therefore, this data shows that longer durations following a dietary switch from high to low NDF diets may be useful to increase yield and improve carcass fatty acid saturation.

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

Ingredient, %	Corn-soybean meal	DDGS[2]
Corn	80.86	61.15
Soybean meal, 46.5% crude protein	15.17	4.61
Corn distillers dried grains with solubles	---	30.00
Choice white grease	1.65	2.00
Calcium carbonate	0.83	1.10
Monocalcium phosphate, 21% P	0.43	---
Sodium chloride	0.45	0.35
L-Lysine-HCl	0.28	0.50
DL-Methionine	0.07	---
L-Threonine	0.11	0.11
L-Tryptophan	0.03	0.06
Phytase[3]	0.03	0.03
Vitamin and mineral premix[4]	0.10	0.10
Total	100.00	100.00
Calculated analysis		
Standardized ileal digestible (SID) amino acids[5], %		
Lysine	0.77	0.77
Isoleucine:lysine	62	61
Leucine:lysine	150	191
Methionine:lysine	36	34
Methionine and cysteine:lysine	64	64
Threonine:lysine	68	68
Tryptophan:lysine	21	21
Valine:lysine	71	77
Total lysine, %	0.87	0.92
Metabolizable energy, kcal/kg	3,402	3,366
Net energy, kcal/kg	2,612	2,612
SID lysine:net energy, g/Mcal	2.95	2.95
Crude protein, %	14.3	16.3
Calcium, %	0.46	0.49
Phosphorus, %	0.41	0.41
Sodium, %	0.21	0.22
Standardized total tract digestible P, %	0.30	0.31

[1] Diets were fed from approximately 100 to 132 kg in Exp. 1 and 105 to 132 kg in Exp. 2 and based on NRC nutrient values.

[2]DDGS = corn distillers dried grains with solubles.

[3]Ronozyme HiPhos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) provided 751 FYT/kg of diet with an assumed release of 0.12% P.

[4]Provided 2,616,860 IU vitamin A from vitamin A acetate, 266,666 vitamin D_3 from cholecalciferol, 523,332 IU vitamin D from 25-hydryoxycholecalciferol, 16,169 mcg vitamin B_{12} from vitamin B_{12} , 5,880 mg riboflavin, 17,637 mg niacin from nicotinic acid, 11,759 mg d-pantothenic acid from dl-pantothenic acid, 1,764 mg

menadione from menadione sodium bisulfate complex, 661 ppm Se from sodium selenite, 33,069 ppm Cu from tri-basic copper chloride, 111,700 ppm Fe from ferrous sulfate, 198,414 ppm Zn from zinc hydroxychloride, 55,115 ppm Mn from manganese hydroxychloride, and 558 ppm I from ethylenediamine dihydriodide per kg of premix.

[5] Calculated using NRC (2012) digestibility coefficients.

Table 3-2. Diet analysis, Exp. 1 and 2[1]

Item, %	Corn-soybean meal	DDGS[2]
Dry matter, %	88.3	89.1
Crude protein, %	14.3	16.6
Acid detergent fiber, %	4.6	5.8
Neutral detergent fiber, %	8.6	12.8
Calcium, %	0.55	0.63
Phosphorus, %	0.40	0.48
Ether extract, %	4.4	5.7

[1] Diets were fed from approximately 100 to 132 kg in Exp. 1 and 105 to 132 kg in Exp. 2.

[2]DDGS = corn distillers dried grains with solubles.

Table 3-3. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on weekly finishing pig performance, Exp. 1[1,2,3]

	Switch from DDGS to CSBM before market, d				
Item[4]	28	21	14	0	Probability, *P* =
BW[5], kg					
d 28	99.6	---	---	99.5	0.961
	0.73	---	---	0.42	
d 21	107.7	107.3	---	107.4	0.947
	0.84	0.84	---	0.59	
d 14	113.4	113.4	112.2	112.2	0.640
	0.93	0.93	0.93	0.93	
d 7	119.9	119.3	118.7	118.7	0.731
	0.92	0.92	0.92	0.92	
Final BW	127.1	126.5	125.6	125.8	---[6]
	0.941	0.941	0.982	0.941	
d 28 to 21					
n (pens):	12	---	---	36	---
ADG[7], kg	1.16	---	---	1.12	0.198
	0.029	---	---	0.017	
ADFI[8], kg	3.02	---	---	3.02	0.981
	0.050	---	---	0.029	
G:F[9]	0.385	---	---	0.372	0.199
	0.0090	---	---	0.0052	
d 21 to 14					
n (pens):	12	12	---	24	---
ADG, kg	1.15[a]	1.15[a]	---	1.04[b]	0.033
	0.039	0.039	---	0.027	
ADFI, kg	2.90	2.80	---	2.78	0.364
	0.065	0.065	---	0.046	
G:F	0.398[ab]	0.409[a]	---	0.373[b]	0.016
	0.0104	0.0104	---	0.0073	
d 14 to 7					
n (pens):	12	12	12	12	---
ADG, kg	0.92	0.85	0.93	0.92	0.272
	0.031	0.031	0.031	0.031	
ADFI, kg	2.89[a]	2.86[a]	2.76[a,b]	2.66[b]	0.027
	0.057	0.057	0.057	0.057	
G:F	0.319[a,b]	0.299[b]	0.338[a]	0.348[a]	0.017
	0.0113	0.0113	0.0113	0.0113	
d 7 to 0					
ADG, kg	1.02	1.02	0.96	1.03	0.259
	0.026	0.026	0.027	0.026	
ADFI, kg	3.02	3.03	3.00	2.93	0.303
	0.038	0.038	0.040	0.038	

G:F	0.338 0.0088	0.337 0.088	0.321 0.0092	0.352 0.0088	0.135

[ab]Means within a row with different superscripts differ, $P < 0.05$.

[1]A total of 985 finishing pigs (initially 99.6 ± 2.5 kg BW) were used in a 28-d experiment to evaluate the effects of switching from diets containing corn DDGS to corn- and soybean meal-based (CSBM) diets at increasing intervals before harvest.

[2] Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3] Pens of pigs were marketed according to a typical summer marketing strategy with one marketed prior to final barn marketing. All pens were marketed by removing the 17% heaviest pigs on d 21 prior to final marketing resulting in a final barn marketing of approximately 83% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] BW = body weight.

[6] Linear, P =0.328; quadratic, P = 0.476.

[7] ADG = average daily gain.

[8] ADFI = average daily feed intake.

[9] G:F = feed efficiency.

Table 3-4. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on carcass characteristics for individual marketing events, Exp. 1[1,2,3]

	Switch from DDGS to CSBM before market, d				Probability, *P* =		
Item[4]	28	21	14	0	Trt	Linear	Quadratic
First marketing (d 21 prior to market)							
HCW[5], kg	89.2	---	---	88.1	0.401	---	---
	1.09			0.62			
Carcass yield, %	73.9	---	---	73.3	0.089	---	---
	0.30			0.17			
Backfat, mm[6]	15.1	---	---	15.7	0.314	---	---
	0.45			0.26			
Loin depth, mm[6]	61.1	---	---	60.4	0.265	---	---
	0.55			0.30			
Lean, %[6]	54.9	---	---	54.5	0.252	---	---
	0.25			0.14			
Final marketing							
HCW, kg	96.6	96.4	95.7	94.6	---	0.061	0.812
	0.80	0.80	0.84	0.80			
Carcass yield, %	76.2	76.0	76.2	75.0	---	0.001	0.055
	0.20	0.20	0.21	0.21			
Backfat, mm[6]	14.8	15.0	15.5	15.1	---	0.225	0.073
	0.21	0.21	0.22	0.21			
Loin depth, mm[6]	63.8	63.1	63.4	62.8	---	0.072	0.631
	0.32	0.33	0.34	0.33			
Lean, %[6]	54.9	54.7	54.6	54.6	---	0.084	0.111
	0.11	0.11	0.12	0.11			
Iodine value	71.0	71.3	71.3	73.0	---	0.001	0.069
	0.26	0.26	0.26	0.25			

[1]A total of 985 finishing pigs (initially 99.6 ± 2.5 kg BW) were used in a 28-d experiment to evaluate the effects of switching from diets containing corn DDGS to CSBM diets at increasing intervals before harvest.

[2]Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3]Pens of pigs were topped according to a typical summer marketing strategy with one top prior to final barn final barn marketing. All pens were topped by removing the 17% heaviest pigs on d -21 resulting in a final barn marketing of approximately 83% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] HCW = hot carcass weight.

[6] Hot carcass weight was used as a covariate.

[7] Belly fat.

Table 3-5. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on overall growth performance and carcass characteristics, Exp. 1[1,2,3]

	Switch from DDGS to CSBM before market, d				Probability, *P* =	
Item[4]	28	21	14	0	Linear	Quadratic
Growth performance						
ADG[5], kg	1.07	1.04	1.02	1.02	0.022	0.202
	0.014	0.014	0.014	0.014		
ADFI[6], kg	2.96	2.92	2.90	2.87	0.112	0.729
	0.041	0.041	0.043	0.041		
G:F[7]	0.361	0.357	0.354	0.357	0.479	0.248
		0.003	0.003			
	0.0037	7	9	0.0037		
Final BW[8], kg	127.1	126.5	125.6	125.8	0.328	0.476
	0.941	0.941	0.982	0.941		
Carcass characteristics						
HCW[9], kg	95.3	94.6	94.1	93.7	0.166	0.702
	0.81	080	0.83	0.81		
Carcass yield, %	75.8	75.5	75.6	74.7	0.001	0.377
	0.18	0.18	0.19	0.18		
Backfat, mm[10]	14.8	15.2	15.6	15.1	0.430	0.019
	0.19	0.19	0.20	0.20		
Loin depth, mm[10]	63.3	62.4	62.9	62.5	0.106	0.388
	0.27	0.27	0.28	0.27		
Lean, %[10]	54.9	54.6	54.5	54.7	0.214	0.033
	0.11	0.11	0.11	0.11		

[1]A total of 985 finishing pigs (initially 99 ± 2.5 kg BW) were used in a 28-d experiment to evaluate the effects of switching from diets containing corn DDGS to CSBM diets at increasing intervals before harvest.

[2] Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3] Pens of pigs were topped according to a typical summer marketing strategy with one top prior to final barn marketing. All pens were topped by removing the 17% heaviest pigs on d -21 resulting in a final barn marketing of approximately 83% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] ADG = average daily gain.

[6] ADFI = average daily feed intake.

[7] G:F = feed efficiency.

[8] BW = body weight.

[9] HCW = hot carcass weight.

[10] HCW was used as a covariate.

Table 3-6. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on weekly finishing pig performance, Exp. 2[1,2,3]

	Switch from DDGS to CSBM before market, d				
Item[4]	35	28	14	0	Probability, *P* =
BW[5], kg					
d -35	105.2	---	---	105.2	0.978
	0.51	---	---	0.30	
d -28	112.6	112.3	---	112.3	0.912
	0.56	0.56	---	0.40	
d -21	117.6	118.2	---	118.3	0.646
	0.65	0.65	---	0.46	
d -14	125.0	125.3	125.0	125.2	0.989
	0.65	0.65	0.65	0.65	
d -7	128.2	128.0	128.9	128.3	0.817
	0.75	0.75	0.75	0.75	
Final BW	135.8	134.9	136.6	136.0	---[6]
	0.81	0.81	0.81	0.81	
d 35 to 28					
n (pens):	15	---	---	45	
ADG[7], kg	1.06	---	---	1.01	0.066
	0.025	---	---	0.014	
ADFI[8], kg	3.09	---	---	2.96	0.007
	0.041	---	---	0.024	
G:F[9]	0.344	---	---	0.343	0.873
	0.0060	---	---	0.0035	
d 28 to 21					
n (pens):	15	15	---	30	
ADG, kg	1.05	1.10	---	1.11	0.135
	0.027	0.027	---	0.019	
ADFI, kg	3.19	3.17	---	3.10	0.164
	0.040	0.040	---	0.029	
G:F	0.328[a]	0.348[b]	---	0.359[b]	0.008
	0.0078	0.0078	---	0.0056	
d 21 to 14					
ADG, kg	1.03[a]	1.02[a]	---	0.96[b]	0.004
	0.021	0.021	---	0.015	
ADFI, kg	3.22[ab]	3.24[a]	---	3.11[b]	0.034
	0.044	0.044	---	0.031	
G:F	0.322	0.315	---	0.309	0.371
	0.0071	0.0071	---	0.0051	
d 14 to 7					
n (pens):	15	15	15	15	
ADG, kg	1.03	1.04	1.10	1.00	0.094
	0.028	0.028	0.028	0.028	
ADFI, kg	3.20[a]	3.20[a]	3.30[a]	3.04[b]	0.001

	0.043	0.043	0.043	0.043	
G:F	0.322	0.326	0.334	0.329	0.862
	0.0010	0.0010	0.0010	0.0010	
d 7 to 0					
ADG, kg	1.10[a]	0.99[b]	1.10[a]	1.11[a]	0.066
	0.034	0.034	0.034	0.034	
ADFI, kg	3.52[a]	3.42[ab]	3.50[a]	3.35[b]	0.086
	0.050	0.050	0.050	0.050	
G:F	0.312[a]	0.290[b]	0.314[a]	0.329[a]	0.003
	0.0071	0.0071	0.0071	0.0071	

[ab]Means within a row with different superscripts differ, $P < 0.05$.

[1]A total of 1,158 finishing pigs (initially 105 ± 2.0 kg BW) were used in a 35-d experiment to evaluate the effects of switching from diets containing corn DDGS to CSBM diets at increasing intervals before harvest.

[2]Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3]Pens of pigs were topped according to a typical winter marketing strategy with two tops prior to final barn marketing. All pens were topped by removing the 15% heaviest pigs on d -28 and the 28% heaviest pigs on d -14 resulting in a final barn marketing of approximately 57% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] BW = body weight.

[6] Linear, P =0.481; quadratic, P = 0.829.

[7] ADG = average daily gain.

[8] ADFI = average daily feed intake.

[9] G:F = feed efficiency.

Table 3-7. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on individual marketing event carcass characteristics, Exp. 2[1,2,3]

	Switch from DDGS to CSBM before market, d				Probability, *P* =		
Item[4]	35	28	14	0	Trt	Linear	Quadratic
First marketing (d 28 prior to market)							
HCW[5], kg	93.7	---	---	92.1	0.132	---	---
	0.86	---	---	0.54			
Carcass yield, %	73.7	---	---	73.4	0.484	---	---
	0.33	---	---	0.20			
Backfat, mm[6]	15.7	---	---	14.4	0.605	---	---
	0.40	---	---	0.25			
Loin depth, mm[6]	61.6	---	---	61.2	0.662	---	---
	0.61	---	---	0.40			
Lean, %[6]	54.4	---	---	54.4	0.980	---	---
	0.23	---	---	0.15			
Second marketing (d 14 prior to market)						---	---
HCW, kg	102.5[a]	101.8[ab]	---	100.6[b]	0.067	---	---
	0.66	0.66	---	0.49			
Carcass yield, %	74.9	74.8	---	74.4	0.302	---	---
	0.30	0.30	---	0.22			
Backfat, mm[6]	16.0	15.5	---	15.4	0.329	---	---
	0.32	0.32	---	0.24			
Loin depth, mm[6]	64.4	64.8	---	64.6	0.895	---	---
	0.60	0.59	---	0.44			
Lean, %[6]	54.2	54.3	---	54.4	0.653	---	---
	0.19	0.19	---	0.14			
Final marketing							
HCW, kg	102.1	101.9	102.6	102.0	---	0.935	0.574
	0.60	0.61	0.60	0.60			
Carcass yield, %	75.3	75.3	75.0	74.8	---	0.022	0.854
	0.19	0.19	0.19	0.19			
Backfat, mm[6]	15.6	16.0	15.5	15.4	---	0.224	0.608
	0.24	0.24	0.24	0.24			
Loin depth, mm[6]	65.5	64.9	65.1	65.0	---	0.629	0.603
	0.38	0.38	0.38	0.38			
Lean, %[6]	54.4	54.2	54.4	54.4	---	0.703	0.577
	0.12	0.12	0.12	0.12			
Iodine value[7]	68.1	69.3	70.1	71.7	---	<.0001	0.971
	0.38	0.38	0.37	0.37			

[1]A total of 1,158 finishing pigs (initially 105 ± 2.0 kg BW) were used in a 35-d experiment to evaluate the effects of switching from diets containing corn DDGS to CSBM diets at increasing intervals before harvest.

[2]Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3]Pens of pigs were topped according to a typical winter marketing strategy with two tops prior to final barn marketing. All pens were topped by removing the 15% heaviest pigs on d -28 and the 28% heaviest pigs on d -14 resulting in a final barn marketing of approximately 57% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] HCW = hot carcass weight.

[6] Hot carcass weight was used as a covariate.

[7] Belly fat.

Table 3-8. Effects of switching from diets containing corn distillers dried grains with solubles to corn- and soybean meal-based diets prior to market on overall growth performance and carcass characteristics, Exp. 2[1,2,3]

	Switch from DDGS to CSBM before market, d				Probability, *P* =	
Item[4]	35	28	14	0	Linear	Quadratic
Growth performance (d -35 to 0)						
ADG[5], kg	1.05	1.04	1.05	1.02	0.116	0.480
	0.012	0.012	0.012	0.012		
ADFI[6], kg	3.22	3.18	3.15	3.10	0.015	0.854
	0.035	0.035	0.035	0.036		
G:F[7]	0.327	0.329	0.334	0.331	0.216	0.223
	0.0026	0.0026	0.0026	0.0027		
Final BW[8], kg	135.8	134.9	136.6	136.0	0.481	0.829
	0.81	0.81	0.81	0.81		
Carcass characteristics						
HCW[9], kg	101.0	100.6	100.8	100.6	0.610	0.913
	0.46	0.47	0.48	0.48		
Carcass yield, %	75.0	74.9	74.7	74.5	0.034	0.898
	0.17	0.17	0.18	0.18		
Backfat, mm[10]	15.7	15.8	15.3	15.5	0.128	0.423
	0.18	0.18	0.19	0.19		
Loin depth, mm[10]	64.7	64.5	64.7	64.2	0.370	0.587
	0.28	0.28	0.29	0.29		
Lean, % [10]	54.3	54.3	54.5	54.3	0.759	0.388
	0.09	0.09	0.10	0.10		

[1]A total of 1,158 finishing pigs (initially 105 ± 2.0 kg BW) were used in a 35-d experiment to evaluate the effects of switching from diets containing corn DDGS to CSBM diets at increasing intervals before harvest.

[2]Pigs were fed diets containing 30% DDGS until the start of the trial. Diets with DDGS during the trial also contained 30%.

[3]Pens of pigs were topped according to a typical winter marketing strategy with two tops prior to final barn marketing. All pens were topped by removing the 15% heaviest pigs on d -28 and the 28% heaviest pigs on d -14 resulting in a final barn marketing of approximately 57% of starting barn inventory.

[4] Standard error of the means are reported below the treatment means.

[5] ADG = average daily gain.

[6] ADFI = average daily feed intake.

[7] G:F = feed efficiency.

[8] BW = body weight.

[9] HCW = hot carcass weight.

[10] HCW was used as a covariate.

Chapter 4 - Effects of medium chain fatty acids as a mitigation or prevention strategy against porcine epidemic diarrhea virus in swine feed

ABSTRACT

Feed has been shown to be a vector for viral transmission. Four experiments were conducted to: 1) determine if medium chain fatty acids (MCFA) are effective mitigants when applied to feed both pre- and post- porcine epidemic diarrhea virus (PEDV) inoculation measured by quantitative reverse transcription polymerase chain reaction (qRT-PCR), 2) evaluate varying levels and combinations of MCFA measured by qRT-PCR, and 3) evaluate selected treatments in bioassay. In Exp. 1, treatments were arranged in a 2×2+1 factorial with main effects of treatment (0.3% commercial formaldehyde product (CF), Sal CURB [Kemin Industries, Inc.; Des Moines, IA] or 1% MCFA blend (Blend) of 1:1:1 C6:C8:C10 [PMI, Arden Hills, MN]) and timing of application (pre- or post-inoculation with PEDV); plus a positive control (PC; feed inoculated with PEDV and no treatment). All combinations of treatment and timing decreased detectable PEDV compared to the PC ($P < 0.05$). Pre-inoculation treatment elicited decreased magnitude of PEDV detection compared to post-inoculation ($P = 0.009$). Magnitude of PEDV detection was decreased for CF compared to Blend ($P < 0.0001$). In Exp. 2, pre-inoculation treatments consisted of: 1) PC, 2) 0.3% CF, 3-5) 0.125 to 0.33% C6:0, 6-8) 0.125 to 0.33% C8:0, 9-11) 0.125 to 0.33% C10:0, 12-15) 0.125 to 0.66% C5:0. Treating feed with 0.33% C8:0 resulted in decreased ($P < 0.05$) PEDV detection compared to all other treatments. Increasing concentration of each individual MCFA decreased PEDV detectability ($P < 0.042$). In Exp. 3, pre-inoculation treatments consisted of :1) PC, 2) 0.3% CF, 3-7) 0.25 to 1% Blend, 8-10)

0.125% to 0.33% C6:0+C8:0, 11-13) 0.125% to 0.33% C6:0+C10:0, 14-16) 0.125% to 0.33% C8:0+C10:0. Treating feed with CF, 0.5% Blend, 0.75% Blend, 1 % Blend, all levels of C6:0+C8:0, 0.25% C6:0+0.25% C10:0, 0.33% C6:0+0.33% C10:0, 0.25% C8:0+0.25% C10:0, or 0.33% C8:0+0.33% C10:0 elicited decreased detection of PEDV compared to PC ($P < 0.05$). Increasing concentration of each MCFA combination decreased PEDV detectability (linear, $P < 0.012$). In Exp. 4, feed was treated pre-inoculation with: 1) no treatment (PC), 2) 0.3% CF, 3) 0.5% Blend, or 4) 0.3% C8:0 and analyzed via qRT-PCR and bioassay. Adding 0.5% Blend or 0.3% C8:0 resulted in decreased PEDV compared to PC and only PC resulted in a positive bioassay. Therefore, MCFA can decrease detection of PEDV in feed. Further, inclusion of lower levels of MCFA than previously evaluated are effective against PEDV.

INTRODUCTION

The introduction of porcine epidemic diarrhea virus (PEDV) to the United States swine herd prompted significant investigation regarding routes of viral transmission. It was validated in both controlled experiments (Dee et al., 2014a; Pasick et al., 2014; Schumacher et al., 2016) and epidemiological studies (Bowman et al., 2015; Aubry et al., 2017) that feed ingredients and complete feed may serve as a vehicle for viral transmission. Thus, feed additives have been explored to reduce or prevent viral transmission in swine feed. Medium chain fatty acids (MCFA), which consist of 6 to 12 carbon atoms, have emerged as a promising technology to disrupt virus activity within feed. Cochrane et al. (2017a) demonstrated the efficacy of MCFA as an effective strategy to decrease detectable genetic material and infectivity in complete swine feed. Adding 1% MCFA blend containing hexanoic (C6:0), octanoic (C8:0), and decanoic (C10:0) acids in a 1:1:1 ratio significantly reduced PEDV detection in swine feed when applied prior to inoculation (Cochrane et al., 2017a). Gebhardt et al. (2018a) also observed a decrease in

detectable virus when feed was manufactured with MCFA and stored for 40 d before inoculation with PEDV. However, there is no information to determine if application of MCFA pre- or post-inoculation is equally effective in reducing viral activity in feed. Further, varying combinations of MCFA and lower inclusion rates that may be more economical have not been thoroughly evaluated. Therefore, the objectives of this set of experiments was to determine: 1) the effects of timing of MCFA application, 2) the impact of varying combinations of different fatty acids and inclusion levels, and 3) the effects of selected MCFA treatments in bioassay.

MATERIALS AND METHODS

Chemical treatments

Chemical treatments included in Exp. 1 were 0.3% commercial formaldehyde-based product (Sal CURB; Kemin Industries, Inc.; Des Moines, IA) and 1% MCFA blend (1:1:1 ratio of C6:0, C8:0, and C10:0, PMI Nutritional Products, Arden Hills, MN) applied either pre- or post-inoculation with PEDV. In all experiments, pre-inoculation chemical treatments occurred 24 h prior to PEDV inoculation. Post-inoculation chemical treatments were applied within 1 h of virus addition then shaken to ensure even dispersion and stored overnight. There were six replications (250 mL bottles) per treatment.

Chemical treatments (administered prior to viral inoculation) included in Exp. 2 were: 1) Non-treated, PEDV inoculated control (positive control), 2) 0.3% commercial formaldehyde (Sal CURB; Kemin Industries; Des Moines, IA), 3) 0.125% C6:0, 4) 0.25% C6:0, 5) 0.33% C6:0, 6) 0.125% C8:0, 7) 0.25% C8:0, 8) 0.33% C8:0, 9) 0.125% C10:0, 10) 0.25% C10:0, 11) 0.33% C10:0, 12) 0.125% C5:0, 13) 0.25% C5:0, 14) 0.33% C5:0, 15) 0.66% C5:0. There were four replications per treatment.

Chemical treatments (administered prior to viral inoculation) included in Exp. 3 were: 1) Positive control, 2) commercial formaldehyde-based product (Sal CURB; Kemin Industries; Des Moines, IA), 3) 0.25% MCFA blend (1:1:1 ratio of C6:C8:C10), 4) 0.375% MCFA blend, 5) 0.500% MCFA blend, 6) 0.750% MCFA blend, 7) 1.0% MCFA blend, 8) 0.125% C6:0 + 0.125% C8:0, 9) 0.25% C6:0 + 0.25% C8:0, 10) 0.33% C6:0 + 0.33% C8:0, 11) 0.125% C6:0 + 0.125% C10:0, 12) 0.25% C6:0 + 0.25% C10:0, 13) 0.33% C6:0 + 0.33% C10:0, 14) 0.125% C8:0 + 0.125% C10:0, 15) 0.25% C8:0 + 0.25% C10:0. There were four replications per treatment.

Treatments for Exp. 4 included: 1) Positive control, 2) 0.3% commercial formaldehyde (Sal CURB; Kemin Industries; Des Moines, IA), 3) 0.5% MCFA blend (1:1:1 ratio of C6:C8:C10), and 4) 0.3% C8. There were three replications per treatment.

Feed preparation and chemical application

A complete swine diet (corn- and soybean meal-based) was manufactured at the O.H. Kruse Feed Technology Innovation Center in Manhattan, Kansas. A new batch of feed was manufactured for each experiment and did not contain specialty ingredients (whey, further processed soybean meal, animal plasma protein or fish products) or antibiotics. Pre-inoculation chemical treatments were applied to 100 g of feed which was then mixed for 15 minutes using a mason jar feed mixer (Central Machine Shop, Purdue University, West Lafayette, IN) with 10 hex nuts to ensure agitation. Then, 22.5 g of treated feed was placed in a polyethylene bottle (250 mL Nalgene, square wide-mouth high-density polyethylene; Thermo Fisher Scientific, Waltham, MA) and stored at ambient temperature for 24 h.

Post-inoculation chemical treatment (Exp. 1 only) occurred for each replication in the 250 mL bottle. Treatment was added within 1 h of inoculation and immediately shaken to ensure dispersion, then stored at ambient temperature for 24 h.

PEDV Isolate and Inoculation

The U.S. PEDV prototype strain cell culture isolate USA/IN19338/2013, passage 9 (PEDV19338) was used to inoculate feed. Virus isolation, propagation, and titration were performed in Vero cells (ATCC CCL-81) as described by Chen et al. (2014). The stock virus contained an initial concentration of 10^5 $TCID_{50}$/ml.

Inoculation was performed at the Kansas State University College of Veterinary Medicine Virology Laboratory (Exp. 1, 2, and 3) and Iowa State University (Exp. 4). All treatments were inoculated using an appropriately sized pipet to ensure even distribution of virus within the feed matrix. Each bottle received 2.5 mL of diluted viral inoculum, resulting in a final PEDV concentration of 10^4 $TCID_{50}$/g of feed. The pre-treatment bottles received viral inoculation 24 h after chemical treatment, whereas the post-inoculation chemical treatments were applied within 1 h of viral inoculation. Bottles were then shaken for 15 s to further distribute virus throughout feed.

Real time PCR analysis

Bottles were stored at ambient temperature and 100 mL of phosphate buffered saline (PBS; pH 7.4, Life Technologies, Grand Island, NY) was placed in each bottle containing 22.5 g of inoculated feed at 24 h post inoculation. Samples were swirled to ensure even mixing and stored at 4° C for 24 h at which point supernatant was collected and stored at -80° C until qRT-PCR or bioassay was performed.

Quantitative real time reverse transcription PCR procedures were conducted as previously described from Gebhardt et al. (2018c). Fifty microliters (µL) of supernatant from each sample was loaded into a deep well plate and extracted using a Kingfisher 96 magnetic particle processor (Fisher Scientific, Pittsburg, PA) and the MagMAX-96 Viral RNA Isolation Kit (Life Technologies, Grand Island, NY) according to the manufacturer's instructions with one modification, reducing the final elution volume to 60 µL. One negative extraction control consisting of all reagents except the sample was included in each extraction. The extracted RNA was frozen at -20° C until assayed by qRT-PCR. Analyzed values indicate cycle threshold (Ct) where virus was detected. Lower values indicate greater magnitude of nucleic acid detection, but not necessarily infectivity.

Bioassay (Experiment 4)

The bioassay procedure was carried out using the same procedures and same pig source used in previously reported studies (Schumacher et al., 2016; Gebhardt et al., 2018: Schumacher et al, 2018). The Iowa State University Institutional Animal Care and Use Committee reviewed and approved the pig bioassay protocol (IACUC #18-390). Fifteen, mixed sex, commercial pigs (10 d of age) were obtained from a sow herd with no prior exposure to PEDV. Pigs were confirmed to be negative for PEDV, porcine delta coronavirus (PDCoV) and transmissible gastroenteritis virus (TGEV) based on fecal swab analysis upon arrival. To further confirm PEDV negative status, blood serum was analyzed for PEDV antibodies by an indirect fluorescent antibody (IFA) assay. All assays were conducted at the Iowa State University Veterinary Diagnostic Lab. Pigs were allowed 2 d of adjustment prior to the bioassay. All pigs were housed individually with 3 pigs serving as the negative control without viral challenge and 3 pigs per treatment for the positive control, 0.3% commercial formaldehyde, 0.5% MCFA blend, and 0.3%

C8:0 treatments. During the bioassay, rectal swabs were collected on d -2, 0, 3, 5, and 7 post inoculation (dpi) from all pigs and tested for PEDV RNA via qRT-PCR. Following humane euthanasia at 7 dpi, cecal contents were collected and tested for PEDV RNA via qRT-PCR.

Statistical Analysis

In all experiments, each 250 mL bottle was considered a replicate experimental unit and data were analyzed using PROC GLIMMIX in SAS (SAS Institute 9.4, Inc. Cary, NC). In Exp.1, qRT-PCR data were analyzed for the fixed effects of chemical treatment or time of application. In Exp. 2 through 4, the fixed effect of pre-inoculation treatment was evaluated. In Exp. 2 and 3, linear and quadratic responses were also evaluated with increasing doses of individual or combination MCFA. These linear and quadratic contracts included the positive control and coefficients were generated using PROC IML to account for unevenly spaced inclusion levels. Results were considered significant at $P < 0.05$ and marginally significant at $P > 0.05$ and $P < 0.10$.

RESULTS

Experiment 1

There was no evidence of an interaction between timing of chemical application and chemical mitigant ($P = 0.326$; Table 1). Treating feed prior to PEDV inoculation resulted in decreased ($P = 0.009$) PEDV detection compared with feed treated with chemical after PEDV inoculation. Also, regardless of time of application, treating feed with a formaldehyde-based product resulted in decreased ($P < 0.001$) PEDV detection compared with MCFA-treated feed (Table 3). All four chemical treatments resulted in decreased ($P < 0.05$) PEDV detection compared to the positive control.

Experiment 2

There was a significant effect ($P < 0.001$) of treatment (applied pre-inoculation) on the detectable PEDV (Table 2). Feed treatment with 0.33% C8:0 resulted in decreased ($P < 0.05$) detectable PEDV compared to all other levels of MCFA, the formaldehyde-based product, and the positive control. Alternatively, formaldehyde-based product, 0.25% C6:0, 0.33% C6:0, all levels of C8:0, 0.25% C10:0, 0.33% C10:0, and 0.66% C5:0 all had decreased magnitude of viral nucleic acid detection compared to positive control feed ($P < 0.05$). Further, increasing C6:0 and C8:0 addition from 0.125 to 0.33% resulted in decreased (linear, $P < 0.001$) PEDV detection. Increasing C10:0 addition resulted in a quadratic decrease in PEDV detection ($P < 0.042$). Lastly, increasing C5:0 from 0.125 and 0.66% resulted in linear decreases in viral detection ($P = 0.001$).

Experiment 3

When evaluating MCFA in combination and varying concentrations applied pre-inoculation, there was a significant effect of treatment ($P < 0.001$; Table 5). Treatments that had significantly decreased ($P < 0.05$) PEDV detection values compared to the positive control feed included: formaldehyde-based product, 0.50% Blend, 0.75% Blend, 1.0% Blend, all levels of C6:0 + C8:0, 0.25% C6:0 + 0.25% C10:0, 0.33% C6:0 + 0.33% C10:0, 0.25% C8:0 + 0.25% C10:0, and 0.33% C8:0 + 0.33% C10:0. Increasing MCFA blend resulted in decreased (linear, $P = 0.001$) viral nucleic acid detection. Increasing combination of C6:0 + C8:0, C6:0 + C10:0, and C8:0 + C10:0 from 0.25 to 0.66% resulted in a significant decrease in PEDV detection (linear, $P < 0.012$).

Experiment 4

The qRT-PCR results demonstrated a significant effect of pre-inoculation chemical treatment on feed ($P < 0.001$; Table 6), with 0.5% MCFA blend and 0.3% C8:0 having increased ($P < 0.05$) Ct compared to the positive control and formaldehyde-based product treatments. For the bioassay, as expected, pigs inoculated with supernatant from negative control did not have positive PEDV bioassay results. Pigs inoculated with positive control feed resulted in PEDV infection. For all other treatments, there was no evidence of PEDV infection detected for fecal swabs and cecal contents.

DISCUSSION

The introduction of PEDV to North American swine herds in 2013 prompted significant research efforts to determine the viral route of transmission. Since then, literature has established that PEDV can be transmitted via feed ingredients and complete feed (Dee et al., 2014a, 2015; Schumacher et al., 2016). Additionally, the minimum infectious dose of PEDV in complete feed may be as low as 5.6×10^1 $TCID_{50}$/g (Schumacher et al., 2016). Given the small amount of virus needed to naturally infect pigs and the high volume of vehicle traffic at many feed manufacturing facilities, it is important to understand viral transmission within feed and feed mills. Equipment surfaces can retain PEDV RNA, and dust containing viral particles has been confirmed infectious *in vivo* (Huss et al., 2017; Gebhardt et al., 2018b). Further, virus has been detected on the interior of feed delivery vehicles in a swine production system (Greiner, 2016). Thus, several strategies have been evaluated to control or mitigate the spread of PEDV in feed manufacturing facilities and supply chains. Point-in-time processes such as pelleting (Cochrane et al., 2017b) or irradiation (Trudeau et al., 2016) may be effective in decreasing detectable genetic material or infectivity, but do not provide lasting protection against potential recontamination. Equipment

sanitation can be effective but is difficult to implement in high volume feed mills (Muckey, 2016). Therefore, feed additives remain a promising strategy to provide long-term protection from contaminated feed, though it is unclear whether treatment should occur before or after viral inoculation.

This is the first data to compare the effects of treating swine feed with mitigants (1% MCFA Blend or 0.3% commercial formaldehyde) either prior to or post-viral inoculation. The majority of literature evaluating feed mitigants incorporates the chemicals prior to viral inoculation (Dee et al., 2014b; Trudeau et al., 2016; Gebhardt et al., 2018c). Efficacy of MCFA or formaldehyde to degrade viral RNA in feed has been demonstrated when feed is treated immediately before inoculation (Cochrane, 2018) and up to 40 d before inoculation (Gebhardt et al., 2018a). It appears from our data that treated feed before or after inoculation will reduce the amount of detectable viral material compared to non-treated feed, yet pre-inoculation treatment increased Ct values beyond those of post-inoculation, though the magnitude of difference was marginal at approximately 1.3 Ct. These results are promising due to the fact that infection can occur at many points in the ingredient procurement, feed manufacturing, and feed delivery process. Some ingredients (blood products) are a high risk for contamination due to being sourced from livestock processing facilities and may have greater affinity to retain PEDV viral activity over a period of time (Dee et al., 2016; Cochrane et al., 2018). However, contamination post-manufacturing is possible via infected equipment or contact surfaces (Schumacher et al., 2017).

Based on evidence that formaldehyde has antimicrobial characteristics (Wales et al., 2013), formaldehyde emerged as a potential PEDV mitigant after the U.S. outbreak. The application of Sal CURB (which is a combination of propionic acid and 37% aqueous

formaldehyde) has been demonstrated to decrease the amount of detectable PEDV compared to infected, untreated feed as well as result in negative bioassay (Dee et al., 2014b; Cochrane et al., 2015). Our PCR and bioassay data support these findings that this source of commercial formaldehyde effectively reduces the magnitude of detectable virus and prevents infection when tested *in vivo*.

Several experiments reported that while commercial formaldehyde provides a notable decrease in detectable viral RNA, a 2% MCFA blend (1:1:1 blend of hexanoic, octanoic, and decanoic acids) also reduced quantifiable PEDV RNA compared to untreated controls (Cochrane, 2015, 2018). However, use of formaldehyde may require specialized equipment and enhanced safety measures. Thus, other additives have been evaluated such as organic acids, essential oils, and MCFA (Reichling et al., 2009; Cochrane et al., 2015; Trudeau et al., 2016; Gebhardt et al., 2018c). After these findings, low inclusion levels were explored, and addition of 1% MCFA blend was found to be as effective as commercial formaldehyde with a bioassay (Cochrane, 2018). Further exploration into individual MCFA showed that application of 0.66% C6:0, C8:0, or C10:0 also resulted in no evidence of PEDV infectivity in bioassays (Cochrane, 2018). The proposed mode of action for this phenomenon is thought to be the disruption of the viral envelope (Thormar et al., 1987; Cochrane, 2018). It is hypothesized that MCFA interact with the lipid bilayer of the envelope to prevent virus attachment to host cells, and ultimately, inhibit viral replication (Cochrane et al., 2018).

The qrt-PCR data in the present experiment is the first of our knowledge to explore MCFA at low inclusion levels (< 0.66%) and combinations in an attempt to determine which, if any, MCFA may be delivering more antiviral activity than others. Our data show that at least 0.25% C6:0, all levels of C8:0, 0.25% C10:0 only, and 0.66% C5:0 resulted in decreased PEDV

Ct values compared to the positive control. Further, 0.5% or greater of the MCFA blend, all levels of C6:0+C8:0 combinations, 0.25% C6:0 + 0.25% C10:0 or greater, and 0.25% C8:0 + 0.25% C10:0 or greater resulted in greater reduction of detectable PEDV compared to the positive control. Evaluating the data from Exp. 2 and 3 together, it appears that C6:0 and C8:0 are providing the majority of the antiviral activity.

Thus, the 0.5% MCFA blend and 0.3% C8:0 were selected for evaluation in bioassay. The lowest concentrations evaluated to our knowledge of MCFA blend (C6:C8:C10) or individual MCFA were 1% Blend and 0.66% C6:0, C8:0, or C:10 (Cochrane et al., 2018). In the current experiment, all chemical treatments and the negative control resulted in no evidence of infectivity via bioassay with feed Ct values ranging from 29.2 to greater than 36. The positive control treatment was the only treatment that resulted in evidence of infectivity via bioassay. Cochrane (2018) treated feed with 0.66% C8:0 and also prevented infection in bioassay. In an experiment by Gebhardt et al. (2017), feed was treated with 0.5% C8 and inoculated 40 days after diet manufacturing, and the reduction in PEDV detection in feed was about 3 Ct. Though this was not fed to pigs in bioassay, this is similar to the present findings as 0.3% C8 increased Ct level by almost 5 Ct. We believe this is evidence that application of 0.5% MCFA blend or 0.3% C8 may render PEDV noninfectious.

These experiments demonstrate that MCFA are effective at reducing detectable PEDV via qRT-PCR both before and after virus inoculation. This is an important finding for the swine industry when considering that feed could be infected either before chemical application due to ingredient contamination or after manufacturing due to mill or equipment contamination. Lastly, we observed that a 1:1:1 blend of hexanoic, octanoic, and decanoic acid remains a promising option to reduce PEDV in feed, preventing infection at 0.5% application level. Individually, C6:0

and C8:0 seem to be delivering a majority of this antiviral activity. The formaldehyde-based product, 0.5% C6:C8:C10 blend in a 1:1:1 ratio, and 0.3% C8:0 prevented infection in bioassay. Further research should continue to validate lower inclusion levels of MCFA to prevent viral transmission in swine feed in order to increase the economic feasibility of their application.

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Table 4-1. Effect of chemical and timing of application in relation to PEDV inoculation on PEDV detection using qRT-PCR (Exp. 1)[1]

		Pre-inoculation		Post-inoculation					
Item	Positive control	MCFA	Formaldehyde-based product	MCFA	Formaldehyde-based product	SEM	Timing × Chemical, $P <$	Timing, $P <$	Chemical, $P <$
qrt-PCR, Ct[2]	26.5[d]	30.6[b]	32.4[a]	28.8[c]	31.5[a,b]	0.46	0.326	0.009	0.001

[1] A total of 30 samples (6 samples per treatment) were used. An initial tissue culture (2.5 mL diluted porcine epidemic diarrhea virus [PEDV] inoculum, 10^5 $TCID_{50}$/mL) was added to 22.5 g of swine diet treated with either a medium chain fatty acid (MCFA) blend or commercial formaldehyde. Positive control = non-chemically treated feed inoculated with PEDV. MCFA treatment consisted of a 1:1:1 blend of C6:C8:C10 (hexanoic, octanoic, and decanoic acids, respectively; PMI, Arden Hills, MN) applied to swine feed at an addition of 1%. Commercial formaldehyde-based product (Sal CURB; Kemin Industries, Inc.; Des Moines, IA) was applied at 0.3%. Pre-inoculation indicates that the chemical treatments were applied before inoculation with PEDV. Post-inoculation indicates that chemical treatments were applied after inoculation with PEDV.

[2] Cycle threshold (Ct) required to detect viral genetic material. A high Ct value indicates less genetic material present.

[abcd] Means with differing superscripts differ $P < 0.05$.

Table 4-2. Effect of treating swine feed with increasing levels of individual medium chain fatty acids on porcine epidemic diarrhea virus detection using qRT-PCR (Exp. 2)[1]

Item	qRT-PCR, Ct[2]	SEM	
Positive control	27.2^{g}	0.35	
Formaldehyde-based product	29.3^{b}		
C6:0			
0.125%	27.8^{defg}	Linear, *P* =	0.001
0.25%	28.9^{bc}	Quadratic, *P* =	0.831
0.33%	29.4^{b}		
C8:0			
0.125%	28.8^{bcd}	Linear, *P* =	0.001
0.25%	29.0^{bc}	Quadratic, *P* =	0.263
0.33%	31.3^{a}		
C10:0			
0.125%	27.7^{efg}	Linear, *P* =	0.146
0.25%	28.4^{bced}	Quadratic, *P* =	0.042
0.33%	27.4^{fg}		
C5:0			
0.125%	27.1^{g}	Linear, *P* =	0.001
0.25%	27.2^{fg}	Quadratic, *P* =	0.578
0.33%	27.3^{fg}		
0.66%	28.3^{cdef}		

[1]A total of 60 samples (4 per treatment) were used. An initial tissue culture (2.5 mL diluted porcine epidemic diarrhea virus [PEDV] inoculum, 10^5 $TCID_{50}$/mL) was added to 22.5 g of swine diet treated with either commercial formaldehyde, or individual levels of C6:0, C8:0, C10:0, or C5:0 (PMI, Arden Hills, MN). Positive control = non-chemically treated feed inoculated with PEDV. Commercial formaldehyde-based product (Sal CURB; Kemin Industries, Inc.; Des Moines, IA) was applied at 0.3%.

[2] Cycle threshold (Ct) required to detect viral genetic material. A high Ct value indicates less genetic material present.

[abcdefg] Means with differing superscripts differ ($P < 0.05$).

Table 4-3. Effect of treating swine feed with increasing levels of medium chain fatty acid combinations on porcine epidemic diarrhea virus detection using qRT-PCR (Exp. 3)[1]

Item	qRT-PCR, Ct[2]	SEM	
Positive control	27.8^{f}	0.72	
Formaldehyde-based product	32.7^{ab}		
MCFA Blend, %			
0.250	29.7^{def}	Linear, *P* =	0.001
0.375	29.4^{def}	Quadratic, *P* =	0.347
0.500	32.3^{abc}		
0.750	31.8^{abc}		
1.000	33.2^{a}		
C6:0 + C8:0, %			
0.125[3]	30.7^{bcde}	Linear, *P* =	0.001
0.25	31.4^{abcd}	Quadratic, *P* =	0.291
0.33	32.7^{ab}		
C6:0 + C10:0, %			
0.125	29.3^{ef}	Linear, *P* =	0.001
0.25	30.4^{cde}	Quadratic, *P* =	0.648
0.33	30.9^{bcde}		
C8:0 + C10:0, %			
0.125	29.4^{ef}	Linear, *P* =	0.012
0.25	31.3^{abcde}	Quadratic, *P* =	0.237
0.33	30.3^{cde}		

[1] A total of 64 samples (4 per treatment) were used. An initial tissue culture (2.5 mL diluted porcine epidemic diarrhea virus [PEDV] inoculum, 10^5 $TCID_{50}$/mL) was added to 22.5 g of swine diet treated with either commercial formaldehyde, 1:1:1 MCFA blend of (C6:C8:C10, resepectively), or combinations of C6:0, C8:0, C10:0. (PMI, Arden Hills, MN). Positive control = non-chemically treated feed inoculated with PEDV. MCFA blend consisted of a 1:1:1 blend of C6:C8:C10 (hexanoic, octanoic, and decanoic acids, respectively; PMI, Arden Hills, MN). Commercial formaldehyde-based product (Sal CURB; Kemin Industries, Inc.; Des Moines, IA) was applied at 0.3%.

[2] Cycle threshold (Ct) required to detect viral genetic material. A higher Ct value indicates less genetic material present.

[3] Percentages listed indicate the level at which each MCFA was added to the feed.

[abcdef] Means with differing superscripts differ ($P < 0.05$).

Table 4-4. Effect of chemical mitigant used to treat swine feed on porcine epidemic diarrhea virus detection and infectivity using qRT-PCR and bioassay (Exp. 4)[1]

		Fecal swabs					
Item	Feed Ct	-2 dpi[3]	0 dpi	3 dpi	5dpi	7 dpi	Cecal content, 7 dpi
Negative control	> 36	---[4]	---	---	---	---	> 36
Positive control	28.0[b]	---	---	+--	++-	+--	25.4[5]
Formaldehyde-based product	29.2[b]	---	---	---	---	---	> 36
0.5% MCFA Blend	32.2[a]	---	---	---	---	---	> 36
0.3% C8	32.9[a]	---	---	---	---	---	> 36

[1] Each treatment was inoculated with the 10^5 $TCID_{50}$/mL PEDV resulting in 10^4 $TCID_{50}$/g PEDV inoculated feed matrix. The PEDV was diluted using PBS and supernatant collected evaluated for infectivity using a 12-d old pig bioassay in three pigs per treatment (10 mL per pig). Positive control = non-chemically treated feed inoculated with PEDV. Commercial formaldehyde-based product (Sal CURB; Kemin Industries, Inc.; Des Moines, IA) was applied at 0.3%. MCFA blend consisted of a 1:1:1 blend of C6:C8:C10 (hexanoic, octanoic, and decanoic acids, respectively; PMI Arden Hills, MN) applied to the feed at a 0.5%.

[2] A cycle threshold (Ct) >36 was considered no evidence of PEDV RNA.

[3] Day post-inoculation.

[4] A (+) indicates evidence of PEDV infectivity and (-) indicates no evidence of infectivity with one symbol per pig

[5] One pig had cecal contents that resulted in 25.4 Ct, while the other two pigs had no evidence of PEDV (Ct >36) in cecal contents.

[ab] Means with differing superscripts within column differ ($P < 0.05$).

Chapter 5 - Implementing a species-specific undergraduate research program

CORE IDEAS

- Undergraduate research provides a platform for connecting classroom concepts with industry-applicable skills within in the applied sciences.
- A discipline-specific undergraduate research program has led to a greater quantity of students exposed to research, careers, and opportunities within the discipline.
- The majority of students who have completed undergraduate research projects within the discipline-specific undergraduate research program have gone on to enter graduate or professional school, indicating the importance of undergraduate research in shaping their career development.
- This approach can be implemented in other animal science disciplines or other applied science programs.

ABSTRACT

Undergraduate research experiences have well-established benefits on undergraduate education, such as improved critical thinking, professional development, and increased interest in graduate studies. In addition, the host faculty can benefit by increasing their research impact and gaining exposure to potential graduate candidates. In the production animal science field, research also allows for additional livestock handling experience outside of the classroom, which is critical for students without agricultural backgrounds. At Kansas State University, the swine nutrition research group developed a swine-specific undergraduate research program. Several different

models for projects are in place to maximize the research experience for students. Steps in the process include recruitment, initial student evaluation, project execution, presentation, evaluation, and post-graduate status update. There are several key roles in this training process, many of which are played by graduate students, which increases leadership training and development of interpersonal and managerial skills. Evidence collected after students have completed the program reiterates the importance of exposing students to not only the scientific method, but the swine and feed industries. Many of the students who complete projects ultimately pursue graduate or veterinary degrees. Even those who choose non-research related careers recognize the value of research and appreciate exposure to the swine industry. This case study will outline aspects of a swine-specific undergraduate research program, which can be applied to any life sciences discipline.

INTRODUCTION

The advantages of undergraduate research are well-demonstrated throughout literature (Lopatto, 2004; Russell et al., 2007; Healey and Jenkins, 2009). The benefits are multi-factored and exist for all parties participating in the program. For the student, undergraduate research provides increased comprehension in the field of study, confidence, and desire to pursue graduate education (Russell et al., 2007). Additionally, critical thinking skills are improved, oral and written communication ability increases, and students develop professionally (Petrella and Jung, 2008). At Kansas State University, Jones and Lerner (2019) established that critical thinking gains are increased for students who complete undergraduate research compared with those that do not. The host program or faculty mentoring students are able to increase their research impact, while the university gains exposure via increased presentations and publications, as well as the ability to provide a more robust undergraduate experience (Petrella

and Jung, 2008). Applied research also allows for hands-on, practical experiences in the field of study. Specifically, in the animal science curriculum, increased numbers of students are originating from urban or suburban backgrounds (Harrison, 2015). This demographic shift makes hands-on activities with livestock, such as research or internships, increasingly critical in addition to traditional classroom training (Sterle and Tyler, 2016; Baranko, 2018). Further, the swine industry, along with many other agricultural sectors, is facing significant challenges in finding, hiring, and retaining employees (Boessen et al., 2018). Thus, it is important to expose students to opportunities within the swine industry during their undergraduate careers.

Faculty at many universities mentor undergraduate students and oversee research projects, yet may not have an official program. Over time, the Kansas State University applied swine nutrition team developed a formalized swine nutrition undergraduate research program (UGRP) that has allowed for an increased number of students to experience swine-based research and the swine industry as well as increased the number of research projects that can be completed. Previously, one to three undergraduate projects were completed per year. With the implementation of the new undergraduate research model, in addition to a course-based research class that provides 20 students access to a research project, 25 to 30 students complete swine-based projects each year. This case-study will review the swine nutrition-specific research program that was developed at Kansas State University, outline key characteristics that contribute to project and student success, and provide anecdotal evidence to support program efficacy. This concept and approach can be applied to any life-science discipline and provide similar student learning gains and program benefits.

DEVELOPMENT OF A SPECIES-SPECIFIC UNDERGRADUATE RESEARCH PROGRAM

Types of projects

One of three individual project models can be selected to provide the best experience for both the student and project mentor. Type of project is based on the undergraduate's talent, prior experience, and time availability. In coordination with the KSU Animal Science and Industry Undergraduate Research Program, students can earn varying levels of course credit based on project involvement. Aligning the swine nutrition undergraduate research program (UGRP) with the departmental research program maximizes student experience and contributes to the departmental goal of increasing the number of undergraduate research experiences. Through this program, students completing projects can enroll in 0 to 3 hours of course credit, with one credit hour representing 45 hours of labor.

The first type of project is a shadow project. In this scenario, the student strictly shadows the graduate student mentor. Typically, this project is already designated as a part of the graduate student mentor's research program, and thus, the undergraduate would not present this data as a stand-alone project. The student is expected to be at all chore activities and data collection days (i.e. pig weighing, sample collection, etc.), but other pre- and post-trial activities, such as animal allotment, data entry and review, feed manufacturing, writing of experimental results, may be up to the student's interest level or mentor's discretion. This type of project is ideal for students that are seeking their first experience with pigs, unsure about research, or not ready for additional responsibility. Depending on the student's time commitment, skill set, and interest, this project may count for course credit and be presented at the KSU Department of Animal Sciences and

Industry Undergraduate Research Symposium, but would not be presented at regional or national scientific meetings.

The next type of opportunity is an add-on project. In this experience, the student is responsible for helping with data collection, but also accompanies the graduate student mentor in the pre- and post-trial activities in order to increase learning opportunities and provide complete exposure to the research process. Oftentimes, this project may be an "add-on" to another research trial, where the graduate student mentor is already conducting an experiment, but additional response criteria can be collected to create an independent research trial for the undergraduate. In one example, a graduate student was conducting a sow feeding trial evaluating sow and litter performance, while an undergraduate collected colostrum samples and had ownership in presenting this data. In another instance, the effect of nursery diets on nursery growth performance was being studied, and the undergraduate student presented fecal scoring data as it related to diet. These projects can be presented at departmental or college-level research forums and competitions, as well as regional or national scientific meetings.

The final type of individual project model is a true independent project. The undergraduate is still supervised by a graduate student mentor, yet the undergraduate is ultimately responsible for the project. This is an ideal project type for projects funded specifically for an undergraduate (i.e. U.S. Pork Center of Excellence Swine Research and Education Experience grant). It is also independent in that it is not included in a graduate student's dissertation. This model is ideal for upperclass students, those who have already completed a shadow project, add-on project, or course-based research project, or graduate school candidates.

Another notable type of project, though not for individual students, is the course-based research project. In this model, approximately 20 students complete a swine research project

within the bounds of a traditional semester class. The swine section is typically offered once per calendar year. The class is lecture- and lab-based, and the lab section consists of on-farm data collection for the experiment. This course began in the fall of 2017 and has significantly increased the number of swine-based undergraduate research projects. Additionally, it provides a mentorship opportunity for a graduate student to be a teaching assistant for the course and increases interaction with research faculty and students. Jones and Lerner (2019) provide further detail on implementing course-based research within the animal sciences and the efficacy of class projects compared to individual projects. Key findings from this data set demonstrate that there is no evidence for difference in critical thinking gains between course-based and stand-alone projects, but that participation in any type of undergraduate research provides improved critical thinking skills compared to students who do not complete a project.

Roles of mentor and research coordinator

In the current undergraduate research model, there are two key graduate students involved in the training process for undergraduate research (Table 1). The undergraduate research coordinator (UGRC) is the graduate student within the swine nutrition program that is responsible for assigning students to projects and mentors and overseeing completion of requirements. The graduate student mentor spends the most one-on-one time with the undergraduate student, and the project may be a part of this student's official research program work. The graduate student mentor in charge of the research project will act as the main advisor for the undergraduate student through the duration of the trial. During the trial, communication is most effective directly between these two parties, involving the undergraduate research coordinator and faculty when needed.

This model is similar to the apprenticeship model described by Hunter et al. (2007), except that the current program relies heavily on graduate students to complete a significant portion of the training process. The benefit of having these graduate student roles in the UGRP is multifaceted. First, it allows the responsibilities of project execution and day-to-day communication to be delegated between multiple parties. Secondly and most notably, it provides critical teaching and leadership experience for the mentor and the UGRC. Though graduate studies provide significant technical training in a given area of expertise, another important focus is development of interpersonal and leadership skills. Many graduate students enter the swine industry or academia, where they obtain leadership roles or are expected to mentor undergraduate students or other employees. Therefore, this experience in teaching an undergraduate, communicating, and project execution is invaluable. Oversight is, of course, provided by faculty members. This also provides the undergraduate with a very real-life taste of graduate school and increases interaction between the graduate student cohort and undergraduates, which is critical if the student is a potential graduate school candidate.

The UGRC was formerly responsible for mentoring all undergraduate projects. Utilizing other swine nutrition graduate students as mentors with oversight and coordination provided by the UGRC has allowed for an increase in the number of projects. It also delegates the onboarding process to several leaders and allows more students to gain experience in teaching and training.

Recruitment and initial student evaluation

Identifying undergraduate students that will be a fit to the program can be one of the most significant challenges. The first step is getting word out about the UGRP. Advertisement is conducted in core undergraduate classes related to the discipline such as principles of feeding, fundamentals of animal nutrition, swine science, etc. Other opportunities for advertisement

include clubs (swine-interest club), departmental or collegiate newsletters, and student welcome events. Additionally, many students are directed to the program through word of mouth.

Once student contact is initiated, an initial meeting between the UGRC and the student takes place. In this meeting, information gathered includes major, career goals, and reasons for interest in swine-related research. Additionally, the student is provided information regarding the swine nutrition research group including but not limited to core faculty, types of projects, and expectations of completing a research project. In this meeting, the UGRC must evaluate students for project readiness, which includes traits such as attention to detail, time management, communication, and relevant research, livestock, or swine-related experiences. Students selected for projects demonstrate these traits as well as leadership abilities, desire to learn, and strong work ethic.

Onboarding

After the student is selected and paired with a mentor, several steps are taken to get the student onboarded and ready for the experiment. First, the student, mentor, and coordinator will review anticipated student learning outcomes (Table 2). Then, the undergraduate will complete required Occupational Health and Safety forms, Institutional Animal Care and Use Committee modules and quizzes, and a Domestic Animal Activity Liability Waiver. They are also provided with a complete list of graduate student and faculty contact information. Lastly, a contract (Table 3) is signed that outlines the anticipated time input for each aspect of the project, procedures for project termination upon second unexcused absence, animal welfare, or biosecurity issues.

When the undergraduate student first visits the Kansas State University Swine Teaching and Research Center, they will be met by their mentor to walk through the biosecurity practices of entering a commercial swine farm. It is especially important to get students who lack pig

experience comfortable with biosecurity steps to establish a good foundation and avoid any biosecurity breeches. This is also an example of how the program can provide real-life experience relevant to the commercial swine industry.

Project execution

In all project types, undergraduates are expected to participate in daily chores and animal care along with the graduate student. Specifically, the undergraduate will visit the farm daily and evaluate feed/water status, health, and environmental quality. Although this is a large time commitment for students, it substantially increases student learning gains by providing livestock experience, understanding how data is impacted by daily decisions during chores, and cultivating a sense of responsibility to the trial. Previously, the student was allowed to decide whether they wanted to participate in farm activities beyond just weigh days. When given the choice, many decided to only attend weigh days, either due to interest level or time commitment. Over time, it was discovered that requiring participation in daily animal care significantly increased the robustness of the project and student learning gains. It increased accountability of student and allowed additional time for discussion with the mentor and learning about pig production.

Exposing the student to all areas of completing a research project (beyond just data collection) is a critical feature of this program and included for add-on and independent projects. Activities completed during the pre-data collection phase in relation to swine nutrition include diet formulation, feed manufacturing, and allotment of pigs. In addition to being critical components of swine nutrition research, these activities increase exposure to swine production and may cultivate interest in the swine industry. Post-data collection activities include analyzing the data, examining outliers, and preparing abstracts and research presentations.

Presenting the project

Presenting the data to a scientific audience allows for broad application and thorough understanding of the research subject. In a review of undergraduate research literature, Linn et al. (2015) reported that students are most often involved in project execution and not data interpretation. The Kansas State University program seeks to deliver a wide-ranging experience, and thus all students completing add-on or independent projects are encouraged to present research abstracts and posters at the Animal Science Research Forum each semester. This component can be as time consuming as completing the project because it is often the student's first exposure to scientific writing and statistics. However, preparing a presentation provides a well-rounded understanding of the data and application of the information.

The KSU Department of Animal Sciences and Industry Undergraduate Research Forum is a unique event that occurs each semester. Students who have completed independent or course-based projects have the opportunity to share their research in the form of poster presentations. It is judged by various faculty, and winners are awarded scholarships. Criteria for judging at this event include many of the aspects recognized at scientific meeting research competitions such as abstract readability, poster organization, materials and methods clarity, communication of results, professionalism, rate of speech, and word choice. This benefits the undergraduate greatly as it may be the first time giving a presentation of a scientific nature. Students who complete shadow, add-on, and independent projects can present at this event.

If the student is presenting an add-on or a standalone project, it will typically be submitted for competition at Midwestern or National Meeting of the American Society of Animal Science. In addition to providing a peer-based competition to showcase their efforts, attending these scientific meetings also exposes students to animal science experts from around

the country. At these meetings, they can connect with industry professionals and begin networking in their desired field. Presenting in this environment develops presentation skills and teaches students how to answer questions.

Undergraduate student and mentor evaluation

Upon completing the project, both the student and mentor fill out surveys evaluating the other party. This is beneficial in providing feedback about any obstacles or areas for improvement. The mentors are asked to evaluate whether the student completed project requirements in a satisfactory manner and provide a letter grade if students are completing the project for credit. The undergraduates are asked to comment on the mentor's communication, helpfulness, preparation, and increasing their desire to learn about the subject. This information helps the UGRC understand how well students are paired with mentors and helps identify areas that can be improved in future projects.

Evaluating the impact of a species-specific research program

It is challenging to quantify student learning gains and benefits. Jones and Lerner (2019) described methods for evaluating critical thinking pre- and post- project and demonstrated that critical thinking can improve with an independent research project. Though improved critical thinking skills are undoubtedly a desired outcome of the UGRP, we have sought to evaluate the impact of the UGRP from a swine industry perspective by collecting anecdotal evidence.

Approximately one year after this program was implemented, students who had conducted projects provided a "status update" and completed a survey on the undergraduate research program. Some students had already graduated, while others were still enrolled in undergraduate. Almost all (78%) students who had graduated were pursuing advanced degrees in either graduate or veterinary school (Figure 1). Areas of discipline include swine nutrition and feed science, both

of which have direct impact on commercial swine production. Many students noted that completing undergraduate research was a significant deciding factor in their desire to continue education and helped them select their field of study. This is similar to findings by Lopatto (2004) which describe that 83% of survey participants planned to complete graduate studies. Further, those who chose industry jobs acknowledged the value of undergraduate research and learned that graduate school was not in their best interest, which is a valuable finding for a young person when making career choices. Other responses from this survey are included in Table 4. Students acknowledged the opportunity to participate in research before committing to graduate school, connecting with the swine industry, and benefits of one-on-one time with their mentor.

CONCLUSION

The development of a swine-specific undergraduate research program has allowed the KSU applied swine nutrition team to increase contribution to undergraduate research goals of the department and university, as well as seek out potential graduate school candidates. Students who have completed the program cite critical thinking, exposure to research practices, experience with pigs, and career selection as useful benefits of the program. Undergraduates who complete the projects regularly pursue graduate or veterinary school and often remain connected to the commercial swine industry. This approach can be applied to other animal science disciplines or applied science programs seeking to increase undergraduate research experiences.

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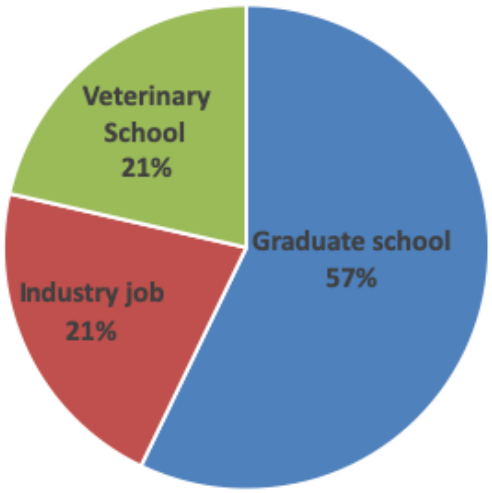

Figure 5-1. Post-project status updates for graduated students who completed undergraduate research.

Table 5-1. Role of undergraduate research coordinator and graduate student mentor

Undergraduate research coordinator
Pair undergraduates with swine nutrition projects and arrange initial meeting of mentor and student to outline expectations and project details.
Openly communicate with undergrad students, graduate students, and faculty, any approaches to improve the dynamics of the coordination process.
Develop a mentor-student relationship ensuring a positive student experience while challenging students to commit to take a project from concept to completion.
Stimulate the development of the student's skill set including: decision making, stockmanship, and personal accountability.
Provide support to the mentor, particularly in the preparation of the undergraduate abstract, poster, and presentation. The undergraduate research coordinator and faculty will be involved in the editing process as well as presentation preparation for each student.
Graduate student mentor
Instruction on day-to-day research tasks.
Fully describe the expectations of the student before the work event begins.
Provide a robust learning experience by thoroughly explaining all processes completed for the project. Take advantage of any opportunity during work events to teach the student by both explanation and demonstration. Although timeliness and efficiency are key in most data collection events, they are secondary to teaching students in this scenario.

Table 5-2. Student learning outcomes

Treatment design and objective of the trial
Basics of diet formulation – major ingredients, formulation alterations for treatments, etc.
Allocation process for animals to pens and pens to treatment
Daily chores and the importance of good animal husbandry as it relates to data integrity
Data collection and how it relates to growth response criteria measured
Data review
Basics of data analysis (What statistical software was used? What types of comparisons were made between treatments? What's the significance level? What does a *P* value mean?)
Technical writing skills and scientific presentation style
Communicate the results to the swine industry and technical audience

Table 5-3. Undergraduate research student contract items

1. Undergraduates that take on a project are expected to participate in **all events** related to the research trial that do not conflict with their class schedule.
2. When you sign up for an event, you are expected to show up accordingly. It is your responsibility to know when and where you are to be for each event.
3. If you cannot help after you have committed (strongly discouraged), you must provide a minimum of 24 h notice to the graduate student in charge of the event. Failure to provide this notice or reoccurring absences will result in a warning and second occurrence will result in termination of student's involvement in the project and/or penalties to the final grade at the discretion of the graduate student mentors and faculty members.
4. Grounds for immediate dismissal: A student's involvement in a project may be terminated at any time with the occurrence of the following events: • Animal cruelty or welfare problems • Breach of biosecurity • Second unexcused absence (first will receive a warning, second results in dismissal)

Table 5-4. Responses from follow up survey for students who completed undergraduate research

“I am currently working at an Equine Hospital where I am able to use the problem solving skills and other such skills I learned during my research here in my job.”
“This helped me gain a greater understanding of the work that goes into and the process of research. I have been able to demonstrate my work ethics and knowledge to prospective employers as a result of completing an undergraduate research project.”
“My experiences helped me figure out I'm interested in a career in swine nutrition research, and also helped prepare me for an internship where I was able to apply and further expand on what I'd learned.”
“I think this is a great opportunity for students to really get a feel for research and see if this is a career or post graduate field that they would like to continue with.”
“I've gained a lot from working with my graduate student mentor and the undergraduate research coordinators I've interacted with; working with them helped to develop some of my first connections within the industry. I also had the chance to engage with my grad student mentor's research beyond the trials I presented on, which helped broaden my research experience significantly, and he's also someone I've been able to ask for advice as I've been working to figure out my plans for grad school and my future in general.”