Effects of lactation and nursery diets supplemented with a feed flavor and increasing tryptophan:lysine ratio in DDGS based diets with or without a DDGS withdrawal strategy in growing-finishing pigs

by

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Abstract

The first chapter of this thesis analyzed the effects of a feed flavor in the sow lactation and nursery diets on sow feed intake and lactation performance and subsequent weaned pig nursery performance. A total of 105 sows were used across four batch farrowing groups. Dietary treatments included a standard corn-soybean-based lactation diet or the control diet with the addition of a feed flavor included at 0.05% of the diet. Overall, sows fed the flavor treatment had a tendency for greater ADFI compared with control sows. In the nursery portion of the study, 360 weaned pigs were used in a 2 × 2 factorial with main effects of previous sow feed flavoring treatment (control vs flavor) and nursery diets formulated with or without a feed flavor on growth performance in a 38-d trial. Offspring from sows fed the flavor diet were heavier at weaning which was maintained throughout the study. Overall, progeny from sows fed a diet containing a feed flavor had greater ADG, ADFI, and final BW during the trial, but the presence of a feed flavor in the nursery did not improve overall nursery performance.

The second chapter compared increasing tryptophan:lysine ratios in DDGS-based diets with or without a DDGS withdrawal strategy on growth performance and iodine value of growing-finishing pigs. A total of 6,240 finishing pigs, divided into 2 groups, were used in a 119 or 120 d study. Pigs were allotted to 1 of 7 treatments consisting of a control corn-soybean meal-based diet formulated to a 19% standardized ileal digestibility Trp:Lys ratio, 4 diets with 30% DDGS fed in all four phases, and formulated to provide SID Trp:Lys ratios of 16, 19, 22, or 25%, and 2 DDGS withdrawal strategy diets with 19% SID Trp:Lys with 30% DDGS in phase 1 through 3 and then 0% DDGS in phase 4 with either a 19 or 25% Trp:Lys ratios. Increasing the SID Trp:Lys ratio in diets with 30% DDGS resulted in a linear increase in ADG, ADFI, G:F, and BW but did not influence carcass fat IV. Removing DDGS from the diet in the last period

reduced carcass fat IV and increased growth rate during the withdrawal period compared to pigs fed 30% DDGS throughout, indicating value in a withdrawal strategy.

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Dedication

This thesis is dedicated to my Grandma Eleanor. You were one of my biggest supporters and the greatest example of how to lead with kindness and care for the people around you. I hope I make you proud every day.

Chapter 1 - Effect of lactation and nursery diets supplemented with a feed flavor on sow feed intake and lactation performance and subsequent weaned pig nursery performance

Abstract

A total of 105 sows (Line 241, DNA, Columbus, NE) were used across four batch farrowing groups to evaluate the effects of feeding a feed flavor in lactation diets on sow and litter performance. Sow groups 1 and 2 farrowed in an old farrowing facility during the summer months and groups 3 and 4 farrowed in a new farrowing facility during the winter months. Sows were blocked by body weight (BW) within parity on d 110 of gestation and allotted to 1 of 2 dietary treatments. Dietary treatments were a standard corn-soybean-based lactation diet (control) or the control diet with the addition of a feed flavor at 0.05% of diet (Krave AP, Adisseo, Alpharetta, GA, USA). Farrowing facility environment had a large impact and resulted in many interactions with the lactation feed flavor treatment. From farrowing to weaning, sows fed the feed flavor in the old farrowing house tended to have a higher (P = 0.058) lactation feed intake, while no difference in ADFI was observed in the new farrowing house. Pigs weaned from sows fed the feed flavor in the old farrowing facility had a higher (P = 0.026) BW at weaning and piglet average daily gain (ADG) from d 2 to weaning (P = 0.001) compared to piglets from sows not fed the feed flavor; whereas the opposite occurred in the new farrowing house. Progeny from one farrowing group in the old farrowing facility was followed into the nursery. A total of 360 weaned pigs (DNA 241 × 600: initially 5.7 kg) were used in a 2 × 2 factorial in the nursery portion of the study to evaluate the effects of previous sow feed flavoring treatment (control vs flavor) and nursery diets formulated with or without a feed flavor on growth performance in a 38-d trial. Nursery treatments were either a control diet or a diet containing a feed flavor (Delistart #NA 21, Adisseo, Alpharetta, GA, USA). Offspring from sows fed the flavor diet were heavier at weaning ($P < 0.001$) which was maintained throughout the study. Overall, progeny from sows fed a diet containing a feed flavor had greater ($P < 0.05$) ADG, ADFI, and final BW during the trial, but the presence of a feed flavor in the nursery did not improve overall nursery performance. In conclusion, when sow lactation feed intake was increased in the old farrowing house, pigs weaned from sows fed the flavor diet were heavier ($P = 0.039$) at weaning compared to pigs weaned from sows fed the control diet. Adding the feed flavor increased sow feed intake and piglet ADG in a warm environment, but not in a cool environment.

List of Abbreviations

ADG = average daily gain

ADFI = average daily feed intake

BW = bodyweight

CP = crude protein

NE = net energy

SID = standardized ileal digestible

WEI = wean to service interval

Introduction

Feed intake of sows during lactation is often below what is needed to meet the demands of milk production (Noblet et al., 1990). During lactation, an increase in feed intake has been shown to reduce backfat and sow body weight (BW) loss and increase litter weight gain (Eissen et al., 2003; Peng et al., 2007). Sow parity and weight, early lactation feed intake, environment, and lactation length affect total sow lactation feed intake (Koketsu et al., 1996). Studies have found that room temperature also greatly impacts feed intake, with an increased room temperature leading to decreased sow lactation feed intake (Black et al., 1993; Gourdine et al., 2006). Temperatures above the upper critical limit, 18 to 22°C, will cause a decrease in metabolizable energy intake (Black et al., 1993; NRC, 2012) and can result in an increase in catabolism of stored fats to meet the energy demands of lactation (Noblet and Etienne, 1987). Decreased feed intake due to increased room temperature leads to a reduction in milk yield, lower piglet weaning weights, and increased sow BW loss (Quiniou and Noblet, 1990).

Feed flavors can stimulate feed intake by using enhanced taste and smell (Roura et al., 2008). The use of feed flavors in the sow lactation diet has been found to increase lactation feed intake, leading to increased milk production and litter weight gain when sows were housed in a tropical, humid environment (Silva et al., 2021). However, in other trials, no differences in feed intake were observed when a feed flavor was used in lactation diets (Charal et al., 2016). In nursery pigs, feed flavors have been shown to improve performance in the early post weaning phase and during heat stress conditions (Fredrick and Van Heugten, 2006). Other studies have shown no differences in average daily feed intake (ADFI) throughout the nursery due to the inclusion of a feed flavor (Sterk et al., 2008; Kim et al., 2019). It has been suggested that piglets can become familiarized with specific flavors used in sow diets because they can pass through the amniotic fluid and milk (Oostindjier et al., 2010). Thus, feeding flavors in nursery pig diets that are like those found in the sow lactation diet have resulted in increased ADFI and average daily gain (ADG) of nursery pigs (Oostindjier et al., 2010; Blavi et al., 2016). This early introduction to feed flavors can be beneficial for newly weaned pigs to entice feed intake and acceptance in the early post weaning period as well as reduce stress and increase postweaning performance (Oostindjer et al., 2011; Oostindjer et al., 2014).

The variable responses observed when including feed flavors in the sow and nursery diet warrants the need for more research to evaluate their effects on sow and litter performance. The first objective of this study was to determine the effect of supplementing a feed flavor product (Krave AP, Adisseo, Alpharetta, GA, USA) in sow lactation diets on sow feed intake, sow weight and backfat change, and litter performance in production facilities and practices typical to the U.S. The second objective was to determine the effect on nursery pig growth performance of supplementing a feed flavor (Delistart #NA 21, Adisseo, Alpharetta, GA, USA) in nursery diets and to determine if pigs weaned from sows that were fed a feed flavor in lactation exhibited improved performance when a similar flavor profile is used in nursery diets. We hypothesized that including a feed flavor in sow diets would increase feed intake and performance of sows. We also hypothesized that piglets fed diets with a similar flavor to that fed in the sow lactation diet would have the greatest improvement in feed intake and gain when compared to piglets fed a standard corn-soybean meal diet.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This trial was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS, USA).

Sows

Animals, Housing, and Treatment

The study began in June 2021, with the first two groups (group 1 and 2) of sows farrowing in June and July 2021. Groups 3 and 4 farrowed in November 2021 and January 2022.

Groups 1 and 2 farrowed in an older farrowing facility (built in 1970) that was environmentally regulated using fans, cooling tubes to direct ambient air onto the sow, and drip coolers to cool sows, whereas groups 3 and 4 farrowed in a new farrowing facility (built in 2021) that utilized evaporative cooling system for incoming air to maintain target temperatures of 21°C. Daily temperature and humidity measurements were taken at a rate of one measurement per hour during lactation using a USB Logger (EasyLog, EL-USB-2, Erie, PA, USA). The average temperature in the farrowing facility for the two groups that farrowed in the summer was 27.9°C (standard deviation = 3.1°C) and the average relative humidity was 62.2% (standard deviation = 10.5%; Table 1). The average temperature in the farrowing facility for the groups that farrowed in the winter was 23.3°C (standard deviation = 0.8°C) and the average relative humidity was 41.4% (standard deviation = 6.1%). Sows in groups 1 and 2 were housed in individual farrowing stalls that measured 1.5 × 2.1 m, that were equipped with a dry self-feeder with feed being delivered, as requested by the sow, through an automated feed system (Gestal Solo Feeder, Jyga Technologies, St-Lambert-de-Lauzon, Quebec, Canada). Sows and piglets had access to a cup water. Sows in groups 3 and 4 were housed in individual farrowing stalls that measured 1.8 × 2.4 m, that were equipped with a dry self-feeder with a similar automated feed system (Gestal Quattro Opti Feeder, Jyga Technologies, St-Lambert-de-Lauzon, Quebec, Canada). Sows and pigs had access to a pan waterer. Creep feed was not offered to piglets during the trial.

A total of 105 mixed parity sows (DNA 241, Columbus, NE, USA) and litters (DNA 241 × 600, Columbus, NE, USA) were used. Sows were blocked by BW within parity and allotted to 1 of 2 dietary treatments in a completely randomized block design. Treatments included a standard corn-soybean-based lactation diet (control) or the control diet with the addition of 0.05% feed flavor (Krave AP, Adisseo, Alpharetta, GA, USA) added at the expense of corn. The feed flavor had a sweet smell like bubblegum. All diets were formulated to meet or exceed the NRC (2012) requirement estimates and were manufactured at Hubbard Feeds (Beloit, KS, USA; Table 2). Sows were fed approximately 2.7 kg of their allotted diet from d 110 until farrowing (approximately d 116) and provided ad libitum access to feed throughout lactation with ad libitum access water granted throughout the feeding period.

Sows were moved to the farrowing facility on d 110 of gestation, at which time they were weighed, backfat was measured using an ultrasound probe (Renco Lean-Meater, Golden Valley, MN, USA), and caliper scores were recorded (Knauer and Baitinger, 2015). Backfat and caliper scores were measured at the last rib, with the backfat probe measurement taken 10 cm from the midline on both sides of the sow and then averaged to derive one composite measurement per sow. After farrowing and weaning, sow weights were recorded with backfat measurements and caliper scores were also recorded at weaning. Feed was provided with the Gestal volumetric feeders and intake was confirmed by feed additions and weigh back of feed tubs at farrowing, d 10, and weaning.

The number of pigs born alive, stillborn, and born mummified were recorded for each sow throughout farrowing. Litters of piglets were cross fostered within treatment group to equalize litter size within 48 h of birth. Litter size and weight was recorded at farrowing, on d 2 and 10 after farrowing, and at weaning. Piglet survivability was determined by dividing the number of piglets weaned by the number of piglets after cross fostering. All piglet mortalities and causes of death were recorded. After weaning, sows were moved to individual gestation stalls and checked daily for signs of estrus using once daily exposure with a boar. The wean-to-service (WEI) interval of each sow was recorded.

Statistical Analysis

Performance data were analyzed as a randomized complete block design using the lmer function from the lme4 package in R (Version 1.4.171, R Core Team Vienna, Austria). Sow and litter were considered the experimental unit. Treatment, farrowing facility, and there interaction were a fixed effect and block (representing sow BW within parity) and sow group was considered a random effect. Litter born alive, stillborn, born mummified, and pre-weaning mortality were analyzed using a binomial distribution with a logit link function. Count of total born, total born alive, and litter size were analyzed using a Poisson distribution. Treatment comparisons were determined considering the interaction of the diet by season and farrowing location (group 1 and 2 vs. group 3 and 4). Four sows on the flavor diet had to be taken off test due to refusing to eat the treatment diet, all were housed in the older farrowing facility during the summer months. Results are considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Nursery

Animals, Housing, and Treatment

A total of 360 weanling pigs (DNA 241 × 600, Columbus, NE, USA: initially 5.7 kg) were used in a 38-d study. Weanling pigs were the offspring of sows fed either a control diet or a diet containing the lactation feed flavor (Krave AP) from d 110 of gestation through the end of lactation. Of the 389 total weaned pigs from the second sow group, 360 healthy pigs with no observable lameness or sickness were used to represent the overall population from both sow treatments. Pigs were weaned at approximately 19 d of age and placed into pens of 5 or 6 pigs and given either a control diet or a diet containing a different feed flavor (Delistart #NA 21, Adisseo, Alpharetta, GA, USA), that had similar flavor compounds to the flavor used in the lactation portion of the study, at 0.05% of the diet added at the expense of corn. Treatments were arranged in a 2 × 2 factorial with main effects of sow treatment (control vs. flavor) and nursery treatment (control vs. flavor). There were 14 to 17 replications per treatment because of differences in the number of pigs weaned between the two sow treatments. Pens were 1.2 × 1.2 m providing pigs with either 0.29 m^2 in pens with 5 pigs or 0.24 m^2 in pens with 6 pigs.

The treatment diets were fed in three phases. The basal phase 1 diet was manufactured at a commercial feed mill (Hubbard Feeds, Beloit, KS, USA), and then evenly divided and the feed flavor or an equivalent amount of corn was added to the control diet at the OH Kruse Feed mill (Manhattan, KS, USA) after which diets were pelleted. Both phase 2 and 3 diets were manufactured as complete feed including the flavor product (Hubbard Feeds, Beloit, KS, USA) and fed in a mash form. Phase 1 was fed until d 9 post weaning, phase 2 from d 9 to 24, and phase 3 from d 24 to 38. Phase 1 diets were formulated to 1.40% SID Lys, and phases 2 and 3 were formulated to 1.35% SID Lys. All other nutrients were formulated to meet or exceed the NRC (2012) requirement estimates.

Pigs and feeders were weighed on d 0, 3, 9, 17, 24, 31, and 38 to determine ADG, ADFI, and G:F. The phase 1 diet contained an indigestible marker, iron oxide, to help determine when pigs started to eat. Starting 10 h after weaning, fecal swabs were taken from all piglets with a cotton tip applicator to determine the percentage of pigs who consumed feed. The color of fecal swabs was used to determine eaters vs non-eaters, with a red tint defined as an eater. Pigs that tested negative on the first sampling were re-sampled every 12 h until all pigs were defined as eaters. Feeders were weighed every day for the first 8-days post weaning to determine feed disappearance during the early post weaning period (figure 1). The percentage of pigs that did not gain weight from weaning to d 3 and from d 3 to d 9 was calculated based on initial weights determined at weaning.

Statistical Analysis

Performance data were analyzed as a randomized complete block design for two-way ANOVA using the lmer function from the lme4 package in R (Version 1.4.171, R Core Team. Vienna, Austria), with pen serving as the experimental unit. Sow treatment, nursery treatment, and the associated interaction were included in the model as fixed effects and room as a random effect. The percentage of pigs defined as eaters were analyzed using a binomial distribution with a logit link function. Daily feed intakes from day 0 to 8 post weaning were analyzed using the lme function in R (Version 1.4.171, R Core Team. Vienna, Austria) using an unstructured covariance matrix for repeated measures including fixed effects of sow treatment, nursery treatment, day, and all associated interactions. Room and pen nested within room were included in the model as random intercepts. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

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Results

Sow

There were interactions observed between dietary treatment and season/farrowing facility for both sow and litter performance (Table 3 and 4). There was a tendency (P = 0.061) for an interaction between sow treatment and season/farrowing facility on sow BW change from entry to farrow with sows fed the control diet in the new farrowing facility during winter having less ($P < 0.05$) BW change compared to those fed the flavor diet, whereas there was no difference ($P > 0.05$) between dietary treatment when sows were housed in the older farrowing facility during the summer months. An interaction was observed for sow ADFI from farrow to d 10 (P = 0.048) as well as tendency from farrow to wean (P = 0.058) where sows fed the diet with the flavor had increased ($P < 0.05$) feed intake in the old farrowing facility in the summer months compared to sows fed the control diet, whereas the opposite was observed when sows were in the new farrowing facility in winter months. A tendency for an interaction for WEI was observed ($P = 0.084$) where feed flavor reduced WEI in the old farrowing facility in the summer, but increased ($0.05 < P < 0.10$) WEI in the new farrowing facility during the winter months. Even though an interaction was found, average WEI only ranged from 4.1 to 4.3 d for all treatments.

Interactions between dietary treatment and season/farrowing facility were found for litter size at d 2, 10, and weaning ($P < 0.05$) where litter sizes did not change in the old farrowing facility ($P > 0.05$), whereas in the new farrowing facility, sows fed diets with flavor had increased litter size. There was an interaction ($P = 0.026$) for litter weight at d 2 with litters from sows fed the flavor diet in the new farrowing facility during winter having greater ($P < 0.05$) d 2 litter weight compared to those litters from sows fed the control diet, there was no difference ($P > 0.05$) in d 2 litter weight when sows were housed in the old farrowing facility during the summer months. An interaction was observed for mean piglet body weight at weaning ($P = 0.026$) where piglet BW increased ($P < 0.05$) when sows were fed the flavor diet in the old farrowing facility in summer months, but decreased ($P < 0.05$) in sows fed the flavor diet in the new farrowing facility in winter months when compared to the control sow litters. There was an interaction ($P = 0.001$) for piglet ADG from d 2 to weaning where piglets from sows fed the flavor diet had a greater ($P < 0.05$) ADG compared to piglets from sows fed the control diet in the old farrowing facility, but the opposite was observed in the newer farrowing facility. There was a tendency for an interaction ($P = 0.095$) for preweaning mortality from birth to d 2, where sows fed the flavor diet tended to have greater piglet mortality ($P < 0.10$) when housed in the old farrowing facility during the summer months while no difference was observed in the new farrowing facility during the winter months. Lastly, an interaction ($P = 0.001$) was observed between treatment and season/farrowing facility environment on preweaning mortality from d 2 to weaning with piglets from sows fed the flavor diet having lower mortality ($P < 0.05$) when housed in the old farrowing facility in the summer months compared to piglets from sows fed the control diet, but higher mortality ($P < 0.05$) when housed in the new farrowing facility in the winter months.

In addition to the interactions, there were main effects observed for season/farrowing facility. There was a tendency ($P = 0.078$) for sows in the new farrowing facility during the cooler winter months to have a higher caliper score at weaning compared to sows housed in the old farrowing facility during the summer months. When sows and litters were housed in the older farrowing facility during the summer months, sow ADFI was lower ($P < 0.05$) overall. Total born was higher ($P = 0.036$) and d 0 litter size was higher ($P = 0.019$) in the older farrowing facility. Piglet BW was lower at d 10 ($P = 0.044$) and litter ($P = 0.019$) ADG was lower in the older farrowing facility during the summer months compared to the newer farrowing facility in the winter months.

Main effects were also observed for feed flavor treatment. When sows were fed diets containing the feed flavor, overall lactation ADFI tended to be greater ($P = 0.093$). Sows fed the control diet, tended ($P = 0.098$) to have a greater percentage of mummies. Day 10 piglet BW of piglets from sows fed the flavor diet tended to be greater ($P = 0.087$) compared to piglets from sows fed control diets. Litter ADG tended ($P = 0.093$) to be greater for piglets from sows fed the flavor diet overall.

Nursery

Progeny from sows fed the feed flavor in lactation entered the nursery at a greater BW ($P < 0.001$; Table 5) than offspring from sows fed the control diet and this BW advantage continued through the end of the study. There were no sow × nursery interactions for BW throughout the 38 d of the trial ($P > 0.10$).

There was no evidence of differences in ADG, ADFI, or G:F from weaning until d 3 postweaning for either sow dietary treatment or nursery flavor addition to diets. From d 3 to 9, pigs fed the flavor diet had increased ($P = 0.022$) G:F compared to those fed the diet without flavor. Offspring from sows fed the flavor diet had increased ADG ($P = 0.038$) and tended to have improved G:F ($P = 0.088$) from d 3 to 9. Overall, for phase 1 (d 0 to 9), there was no difference in ADG or ADFI between treatments but piglets fed diets containing flavor tended to have increased G:F ($P = 0.078$).

During phase 2 (d 9 to 24), there was a tendency for a main effect of both sow ($P = 0.054$) and nursery ($P = 0.052$) treatment to impact ADG where piglets obtained from sows fed the flavor diet had greater ADG compared to piglets from sows fed the control diet and piglets fed the diet without flavor had increased ADG compared to pigs fed the flavor diet. A tendency ($P = 0.094$) for a main effect of sow treatment was found for ADFI with pigs from sows fed the flavor diet having a greater ADFI. There was no differences for G:F during phase 2.

During phase 3 (d 24 to 38), there was a tendency ($P = 0.075$) for an interaction of sow and nursery flavor treatment for ADG where progeny from sows fed flavor diets that were also fed flavor in nursery diets had improved ADG compared to those that did not have flavor in nursery diets, whereas there was no difference between nursery treatments from piglets obtained from the sows fed the control diet. There was a tendency ($P = 0.064$) for pigs from sows fed the flavor diet to have an improved ADFI and pigs fed the flavor diet having (P = 0.010) greater ADFI during phase 3. However, pigs fed the flavor diet also had decreased (P = 0.036) G:F compared to pigs fed the control diet without flavor.

For the overall period, d 0 to 38, piglets from sows that were fed the feed flavor had increased ADG (P = 0.038), ADFI (P = 0.043), and BW (P < 0.001) when compared to piglets from sows that were fed the diet without flavor. There were no overall differences in performance based on the presence or absence of feed flavor in the nursery diets.

No differences were found for early postweaning feed intake from d 0 to 9 postweaning due to nursery (P = 0.326) or sow (P = 0.467) treatment. Difference between days were observed (P < 0.001), with feed intake the highest 6 days postweaning (Figure 1). There was a tendency for a sow treatment by day interaction (P = 0.061) for feed intake post weaning (Figure 2). There was no difference in the number of hours it took pigs to begin eating after weaning based on nursery (P = 0.714) or sow (P = 0.979) treatment (Figure 3). The mean amount of time it took for the marker to be detectable in feces was 75 h (3.1 d) after weaning. There was a tendency (P = 0.073) for an effect of sow treatment on number of pigs that did not gain weight from d 0 to 3 with fewer piglets from sows on the control diet not gaining weight when compared to piglets from sows on the flavor diet (Figure 4). From d 3 to 9, there was a tendency (P = 0.079) for an interaction between sow and nursery treatment with piglets from sows fed the control diet that were fed nursery diets with flavor having increased percentage of pigs with no weight gain, but piglets from sows fed the flavor diet had reduced percentage of pigs without weight gain when nursery diets contained flavor.

Discussion

Feed flavors can be included in swine diets to stimulate feed intake through enhanced taste and smell (Frederick and Van Heugten, 2006). The use of feed flavors to increase feed intake has been variable in all production phases (McLaughlin et al., 1983). Silva et al. (2018; 2021) conducted two studies in tropical climates evaluating the same lactation feed flavor tested in our trial and observed similar outcomes to the summer portion of our study, including an increase in sow ADFI and piglet ADG. Other trials using different feed flavors have also observed similar responses (He et al., 2017; Wang et al., 2021). This association with increased sow feed intake and increased piglet and litter weight and ADG is expected (Koketsu et al., 1996; Eissen et al., 2003) and is the result of increased milk production which is the biggest factor for increased pre-weaning piglet growth (Solà- Oriol and Gasa, 2017). Counter to our observations, Silva et al. (2021) conducted a study in two different environmental conditions, defined as hot and cool, and concluded that the addition of a feed flavor in the sow lactation diet could increase sow feed intake regardless of temperature. Silva et al. (2018) observed that as the concentration of flavor (Krave AP; Adisseo, Alpharetta, GA, USA) increased in the diet from 0.025% to 0.05%, feed intake increased, with sows fed the 0.05% flavor diet having greater intake than sows fed the control diet, with sows fed 0.025% fed flavor being intermediate. Zhe et al. (2022) also conducted a study evaluating the effects of the same feed flavor (Krave AP; Adisseo, Alpharetta, GA, USA) in the sow lactation diet compared to a control diet and found no differences in feed intake between treatments, although litters from sows fed the diet containing the feed flavor had greater ADG than the control. Collectively, the data suggests that feed flavors have the potential to increase sow feed intake and litter gain, but there is not consistency across reports which warrants further investigation into the factors that need to be present for the benefit to be observed.

Voluntary feed intake of sows may be reduced by high environmental temperatures (NRC, 2012), which was observed in our study. The reduction in feed intake in a warmer environment agrees with the findings of Gourdine et al. (2006) and Silva et al. (2009) where warmer environmental temperatures decreased feed intake. Temperatures above the upper critical limit of 18 to 22°C will decrease feed intake (Black et al., 1993; NRC, 2012). During the summer months, the average temperature in the old farrowing house was 27.9°C, above the upper critical limit by almost 6°C. Feed intake was significantly greater in the new farrowing house during the winter months when the average temperature was 23.3°C.

In our study, sows lost BW and backfat from entry to weaning regardless of treatment or farrowing environment. Wang et al. (2014), Silva et al. (2018), and Wang et al. (2021) also fed lactating sows flavored diets and observed backfat losses regardless of treatment. The loss of backfat from entry to weaning indicates that sows were in a negative energy balance. He et al. (2017) observed that adding flavors to the lactation diet decreased sow weight loss. A greater loss of BW and backfat has been associated with larger litter size due to sow's mobilizing body reserves to meet the demands of milk production (Eissen et al., 2003). Sows housed in the old farrowing house fed the flavor diet had a shorter WEI compared to sows fed the control diet, but the opposite was observed in the new farrowing house. However, only slight numerical differences in WEI were observed. Silva et al. (2018) found no differences in WEI; however, He et al. (2017) observed a decreased WEI when sows were fed diets containing a flavor product.

In phases 1 and 2 in the nursery portion of the study, no differences in ADFI were observed due to dietary treatment, but in phase 3 pigs fed the flavor diet had increased ADFI.

Conversely, Sulabo et al. (2010b) and Seabolt et al. (2010) observed increased feed intake during the early post weaning phase with no improvements in ADFI in later phases due to the inclusion of a feed flavor. Blavi et al. (2016) observed positive responses in overall ADFI when a feed flavor was included in the diet. Sterk et al. (2008) observed no differences in ADFI throughout the nursery due to the inclusion of a feed flavor, but numerical differences showed an increase in ADFI for piglets fed the feed flavor throughout the nursery phase. Kim et al. (2019) observed no differences in ADFI or G:F, but found a tendency for an increase in ADG when a feed flavor was included in the diet. In a second experiment, Kim et al. (2019) observed pigs fed a flavor diet had greater ADG and a tendency for increased ADFI, but no differences in G:F using the same flavor product as the first experiment by Kim et al. (2019). Sulabo et al. (2010) evaluated the effects of a feed flavor in a complex vs simple diet. The results of the study indicated that the addition of a feed flavor in a complex diet increased post weaning feed intake but not in a simple diet. This demonstrates the variable response of the inclusion of feed flavor products on growth performance and the impact diet composition has on the response observed. No differences in overall ADG, ADFI, or G:F were observed due to the inclusion of the feed flavor in the nursery diet, which is in agreement with Sterk et al (2008), Sulabo et al. (2010a), and Perez-Palencia et al. (2021) who also saw no differences in growth performance due to the inclusion of a feed flavor. Both ADG and ADFI were greater in pigs from sows fed the flavor diet regardless of nursery dietary treatment in the current study, which was expected because they started the trial almost 0.5 kg heavier. These results are consistent with the results of Blavi et al. (2016), where the inclusion of a feed flavor in the sow lactation diet resulted in greater piglet growth performance post weaning regardless of nursery treatment.

We hypothesized that newly weaned pigs would begin eating feed faster if a flavor was included in the feed. However, as demonstrated in figure 1, the time it took piglets to start eating post-weaning, measured by how long it took the ingestible marker, iron oxide to be visibly noticed in the feces, was not affected by dietary treatment. Strek et al. (2008) also observed no differences in the time it took piglets to begin eating post-weaning in diets with and without a feed flavor. Beaulieu et al. (2010) observed pigs that were weaned at a lighter weight lost less weight immediately post-weaning compared to pigs that were weaned at a heavier weight, which was also observed in this study.

Improved ADFI and ADG in the early post weaning period have been previously observed due to early exposure to feed flavors pre-weaning (Yan et al., 2011; Wang et al., 2014). However, these studies provided exposure to the flavor through sow's milk and in creep feed. Yan et al. (2011) provided a feed flavor in the creep feed from d 5 of lactation to weaning and Wang et al. (2014) from d 7 of lactation to weaning, with the feed flavor also being fed in the lactation diet during both studies. Blavi et al. (2016) analyzed the presence of the flavor compounds in the sow milk and amniotic fluid. The flavor compounds were fed in the sow diet from d 73 of gestation to d 28 of lactation. It was found that the flavor compounds had a higher detection rate in amniotic fluid compared to milk. These findings could explain why there was not an interaction between sow diet and nursery diet, with piglets from sows fed the flavor diet that were fed the flavor diet in the nursery having a higher ADFI. The same flavor product may need to be included in the gestation diet or in creep feed to see a greater positive effect due to early introduction to flavors.

Conclusion

In conclusion, sows fed the flavor diet in the old farrowing house during the summer months had a higher lactation feed intake. The differences in feed flavor response between season and environment suggests that adding Krave AP to the lactation diet in situations where sow lactation ADFI is lower than optimal could lead to improvements in sow and litter performance. Offspring from sows fed a diet containing a flavor had increased overall post-weaning ADG, ADFI, and BW, which are all likely related to the increased weaning weight. Pigs fed the feed flavor during the nursery portion of the trial had increased ADFI for phase 3 of the study, but overall, no treatment differences were observed based on the presence of a feed flavor in nursery diets.

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Table 1-1 Farrowing environment temperature and humidity by group

	Farrowing environment[1]			
	Old/Summer		New/Winter	
	Group 1	Group 2	Group 3	Group 4
Temperature, °C				
Minimum	22.2	23.3	21.1	18.9
Maximum	34.4	37.2	25.6	25.0
Average	27.5	28.2	22.9	23.6
Standard deviation	3.0	3.1	0.7	0.8
Humidity, %				
Minimum	32.5	38.0	28.5	25.0
Maximum	79.5	84.0	66.0	54.0
Average	59.1	65.2	44.3	38.5
Standard deviation	11.2	9.8	6.3	5.8

[1]Two different farrowing facilities were used in this study. Sow groups 1 and 2 were farrowed in an older farrowing facility in June and July 2021, and groups 3 and 4 were farrowed in a new farrowing facility in November 2021 and December 2022.

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

Item	Lactation diet[1]	Nursery phase 1[2]	Nursery phase 2	Nursery phase 3
Ingredients, %				
Corn	64.50	44.50	58.41	64.74
Soybean meal	30.00	18.44	25.49	31.29
Milk, whey powder	--	25.00	10.00	--
Fish meal	--	4.50	--	--
Microbially-enhanced soy protein[3]	--	3.00	2.00	--
Corn oil	2.00	1.50	--	--
Calcium carbonate	0.90	0.30	0.90	0.85
Monocalcium P (21% P)	1.15	0.48	1.10	1.00
Sodium chloride	0.50	0.30	0.55	0.60
L-Lys-HCl	0.20	0.43	0.53	0.52
DL-Met	0.05	0.21	0.22	021
L-Thr	0.07	0.18	0.22	0.22
L-Trp	0.01	0.05	0.05	0.05
L-Val	--	0.12	0.14	0.13
Vitanim premix with phytase[4]	0.25	0.25	0.25	0.25
Trace mineral premix[5]	0.15	0.15	0.15	0.15
Sow premix[6]	0.25	--	--	--
Iron oxide	--	0.60	--	--
Feed flavor[7]	+/-	+/-	+/-	+/-
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Standardized ileal digestibility AA, %				
Lys	1.07	1.40	1.35	1.35
Ile:Lys	67	57	55	55
Leu:Lys	140	111	112	114
Met:Lys	30	37	36	36

Met and Cys:Lys	56	57	57	57
Thr:Lys	63	63	63	63
Trp:Lys	20.7	20	20	20
Val:Lys	73	70	69	69
His:Lys	44	32	34	36
Total Lys, %	1.21	1.54	1.48	1.49
NE, kcal/kg	2,511	2,571	2,449	2,445
SID Lys:NE, g/Mcal	4.25	5.44	5.51	5.57
CP, %	19.9	21.1	20.5	21.2
Ca, %	0.77	0.69	0.77	0.69
P, %	0.63	0.66	0.65	0.61
STTD P, %	0.52	0.61	0.56	0.50

[1]Feed was manufactured by a commercial feed mill (Hubbard Feeds: Beloit, KS).

[2]Phase 1 diets were fed from d 0 to 9 (approximately 5.7 to 6.5 kg BW), phase 2 were fed from d 9 to 24 (approximately 6.5 to 11.0 kg BW), and phase 3 were fed from d 24 to 38 (approximately 11.0 to 19.7 kg BW).

[3]Access starter protein-V, Hubbard Feeds, Mankato MN.

[4]Ronozyme HiPhos GT 2700 (DSM Nutritional Products, Parsippany, NJ) provided 1,248 FTU/kg and an expected STTD P release of 0.14%. Provided per kg of premix: 1,653,468 IU vitamin A; 661,387 IU vitamin D; 17,637 IU vitamin E; 272 mg vitamin K; 3 mg vitamin B12; 4,082 mg niacin; 2,268 mg pantothenic acid; 680 mg riboflavin.

[5]Provided per kg of premix: 73 g Zn from Zn sulfate; 73 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.20 g I from calcium iodate; 0.20 g Se from sodium selenite.

[6]Provide per kg of premix: 1,653,468 IU vitamin A; 8,818 IU vitamin E; 18 mg biotin; 181 mg folic acid; 45,359 mg choline; 4,082 mg carnitine, 0.79 g Cr.

[7]Krave AP in lactation diets and Delistart #NA 21 in nursery diets (Adisseo, Alpharetta, GA, USA) were included at 0.05% in feed flavor diets, added at the expense of corn.

Table 1-3 Interactive effects of lactation diets with or without a feed flavor and farrowing facility environment on sow performance[1]

	Farrowing environment[2]					P =		
	Old/Summer		New/Winter					
	Control[3]	Flavor	Control	Flavor	SEM	Flavor × farrowing facility	Flavor	Farrowing facility
Count, n	27	23	28	27				
Parity	2.5	2.5	2.5	2.5	0.42	0.376	0.266	0.997
Lactation length, d	19.0	19.1	18.8	19.2	0.20	0.525	0.908	0.491
Sow BW, kg								
Entry	262.9	265.9	261.9	262.9	11.00	0.762	0.640	0.949
Farrow	238.1	241.4	242.9	238.5	10.53	0.236	0.286	0.748
Wean	227.9	229.1	231.6	230.8	10.83	0.807	0.807	0.814
Sow BW change, kg								
Entry to farrow	-24.9	-24.4	-17.7	-24.5	2.77	0.061	0.208	0.073
Farrow to wean	-10.1	-11.6	-13.1	-7.7	2.81	0.189	0.317	0.414
Entry to wean	-35.0	-36.2	-30.6	-32.3	3.47	0.945	0.922	0.360
Sow back fat, mm								
Entry	15.2	14.8	15.5	15.4	0.42	0.686	0.566	0.575
Wean	13.5	12.8	14.0	13.7	0.44	0.707	0.473	0.370
Change (entry to wean)	-1.7	-1.9	-1.5	-1.7	0.36	0.973	0.821	0.668
Sow caliper score								
Entry	15.9	15.6	16.1	16.3	0.31	0.450	0.437	0.527
Wean	14.0	13.5	14.8	14.7	0.36	0.629	0.453	0.078
Change (entry to wean)	-1.9	-2.1	-1.3	-1.6	0.28	0.821	0.911	0.107
Sow ADFI, kg								
Pre-farrow	2.8	2.9	2.7	2.8	0.12	0.890	0.908	0.216
Farrow to d 10	4.3	4.7	6.6	6.3	0.22	0.048	0.052	< 0.001
d 10 to wean	6.1	6.5	8.7	8.6	0.28	0.256	0.205	< 0.001

Farrow to wean	5.1	5.5	7.6	7.4	0.21	0.058	0.052	< 0.001
Overall	4.7	5.0	6.5	6.4	0.18	0.125	0.093	< 0.001
Wean-to-estrus interval, d	4.2	4.1	4.1	4.3	0.09	0.084	0.171	0.326

[1]A total of 105 mixed-parity sows (Line 241, DNA, Columbus NE) and litters were used from day 110 of gestation until weaning.

[2]Two different farrowing facilities were used in this study. Sow groups 1 and 2 were farrowed in an older farrowing facility in June and July 2021, and groups 3 and 4 were farrowed in a new farrowing facility in November 2021 and December 2022.

[3]Sow treatment consisted of providing a control diet or the control diet with added Krave AP at 0.05% of diet (Adisseo, Alpharetta, GA, USA) from entry into the farrowing facility (d 110 of gestation) until weaning.

Table 1-4 Interactive effects of lactation diets with or without a feed flavor and farrowing facility environment on litter performance[1]

	Farrowing environment[2]					*P* =		
	Old/Summer		New/Winter					
	Control[3]	Flavor	Control	Flavor	SEM	Flavor × farrowing facility	Flavor	Farrowing facility
Litter characteristics								
Total born, n	17.0	17.6	14.3	16.7	0.92	0.140	0.500	0.036
Born alive, %	90.2	91.0	90.4	88.5	0.02	0.354	0.438	0.911
Stillborn, %	6.8	8.2	6.3	9.5	0.01	0.527	0.967	0.790
Mummy, %	2.6	0.6	2.9	1.6	0.01	0.297	0.098	0.796
Litter size, n								
d 0	15.3	15.9	12.8	14.8	0.76	0.246	0.691	0.019
d 2	14.8	14.8	12.3	14.3	0.34	< 0.001	0.012	< 0.001
d 10	14.0	14.1	12.1	13.6	0.26	0.002	0.063	< 0.001
Wean	13.5	13.7	12.0	13.4	0.27	0.027	0.238	< 0.001
Litter weight, kg								
d 2	24.2	24.4	20.2	23.1	0.79	0.026	0.188	< 0.001
d 10	44.8	47.7	43.3	47.4	1.74	0.650	0.668	0.533
Wean	69.9	74.5	73.2	76.8	2.65	0.802	0.360	0.380
Mean piglet BW, kg								
d 2	1.6	1.7	1.6	1.6	0.06	0.613	0.642	0.879
d 10	3.2	3.4	3.6	3.5	0.13	0.111	0.087	0.044
Wean	5.2	5.5	6.1	5.8	0.22	0.026	0.039	0.005
Litter ADG d 2 to wean, kg/d	2.40	2.62	2.82	2.80	0.12	0.162	0.093	0.019
Piglet ADG d 2 to wean, g/d	177	194	236	212	10.02	0.001	0.005	< 0.001
Preweaning mortality, %								
Birth to d 2	2.8	6.2	3.4	3.2	0.01	0.095	0.038	0.680
d 2 to wean	8.7	6.4	2.0	7.4	0.02	0.001	0.005	0.001

[1]A total of 105 mixed-parity sows (Line 241, DNA, Columbus NE) and litters were used from day 110 of gestation until weaning. Litters were cross fostered to equalize litter size up to 48-h post farrowing within treatment group.

[2]Two different farrowing facilities were used in this study. Sow groups 1 and 2 were farrowed in an older farrowing facility in June and July 2021, and groups 3 and 4 were farrowed in a new farrowing facility in November 2021 and December 2022.

[3]Sow treatment consisted of providing a control diet or the control diet with inclusion of Krave AP at 0.05% of diet (Adisseo, Alpharetta, GA, USA) from entry into the farrowing facility (d 110 of gestation) until weaning.

Table 1-5 Interactive effects of sow and nursery pig diets supplemented with a feed flavor on growth performance of nursery pigs[1]

	Sow treatment[2]							
	Control		Flavor			*P* =		
Nursery treatment[3]	Control	Flavor	Control	Flavor	SEM	Sow × nursery	Sow	Nursery
Body weight, kg								
d 0	5.4	5.5	6.0	6.0	0.03	0.986	<0.001	0.140
d 3	5.6	5.7	6.1	6.1	0.05	0.879	<0.001	0.482
d 9	6.1	6.2	6.7	6.8	0.06	0.904	<0.001	0.147
d 24	10.7	10.6	11.5	11.4	0.19	0.908	<0.001	0.359
d 38	19.3	19.2	20.1	20.4	0.25	0.336	<0.001	0.687
d 0 to 3								
ADG, g	63	63	47	43	15.4	0.863	0.118	0.846
ADFI, g	85	86	79	75	7.0	0.690	0.171	0.847
G:F g/kg	649	677	526	508	130.7	0.836	0.196	0.968
d 3 to 9								
ADG, g	87	96	99	109	87.1	0.999	0.038	0.115
ADFI, g	217	212	228	217	11.7	0.687	0.228	0.246
G:F, g/kg	404	452	437	499	27.3	0.762	0.088	0.022
Phase 1 (d 0 to 9)								
ADG, g	79	85	82	87	6.9	0.906	0.711	0.370
ADFI, g	173	170	178	170	9.7	0.654	0.630	0.326
G:F, g/kg	453	495	455	504	26.2	0.886	0.829	0.078
Phase 2 (d 9 to 24)								
ADG, g	305	288	319	305	13.0	0.813	0.054	0.052
ADFI, g	462	448	485	467	18.1	0.876	0.094	0.184
G:F, g/kg	661	646	657	654	10.8	0.565	0.830	0.357
Phase 3 (d 24 to 38)								
ADG, g	573	568	571	602	12.3	0.075	0.111	0.210
ADFI, g	792	808	796	861	16.2	0.111	0.064	0.010

G:F, g/kg	724	703	719	701	11.8	0.859	0.677	0.036
Overall								
ADG, g	356	347	361	369	6.5	0.194	0.038	0.933
ADFI, g	523	521	534	550	10.3	0.360	0.043	0.479
G:F, g/kg	682	668	677	672	8.0	0.565	0.947	0.222

[1]A total of 360 weaned pigs (600 × 241, DNA, initially 5.7 kg) weaned at approximately 19 d of age were used in a 38-day nursery trial with 5 or 6 pigs per pen and 14 to 17 pens per treatment.

[2]Sow treatment consisted of providing a control diet or a feed flavor diet with inclusion of Krave AP at 0.05% of diet (Adisseo, Alpharetta, GA, USA) from d 110 of gestation until weaning.

[3]Nursery treatment consisted of providing a control diet or a feed flavor diet with the inclusion of Delistart #NA 21 at 0.05% of diet (Adisseo, Alpharetta, GA, USA) in phase 1, 2, and 3.

Figure 1-1 Day 1 to 9 post weaning average daily feed intake

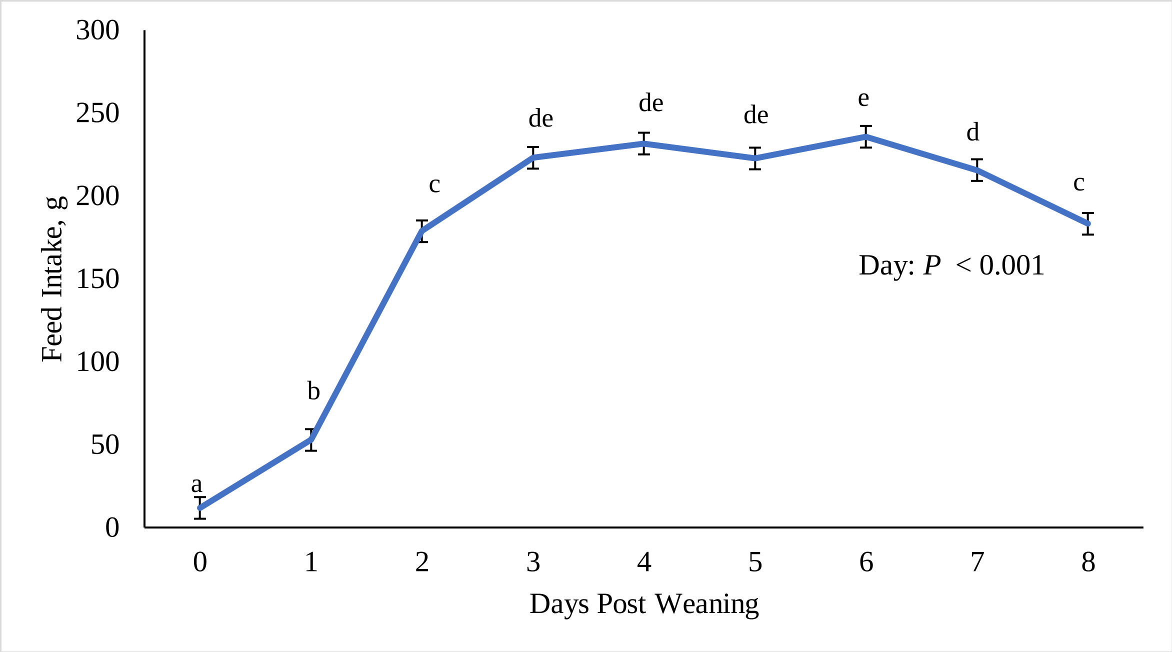

Figure 1-1: Feeders where weighed for 9 days post weaning to determine ADFI in the early postweaning phase

Figure 1-2 : Day 1 to 9 post weaning average daily feed intake of piglets weaned from sows fed the control vs the flavor treatment

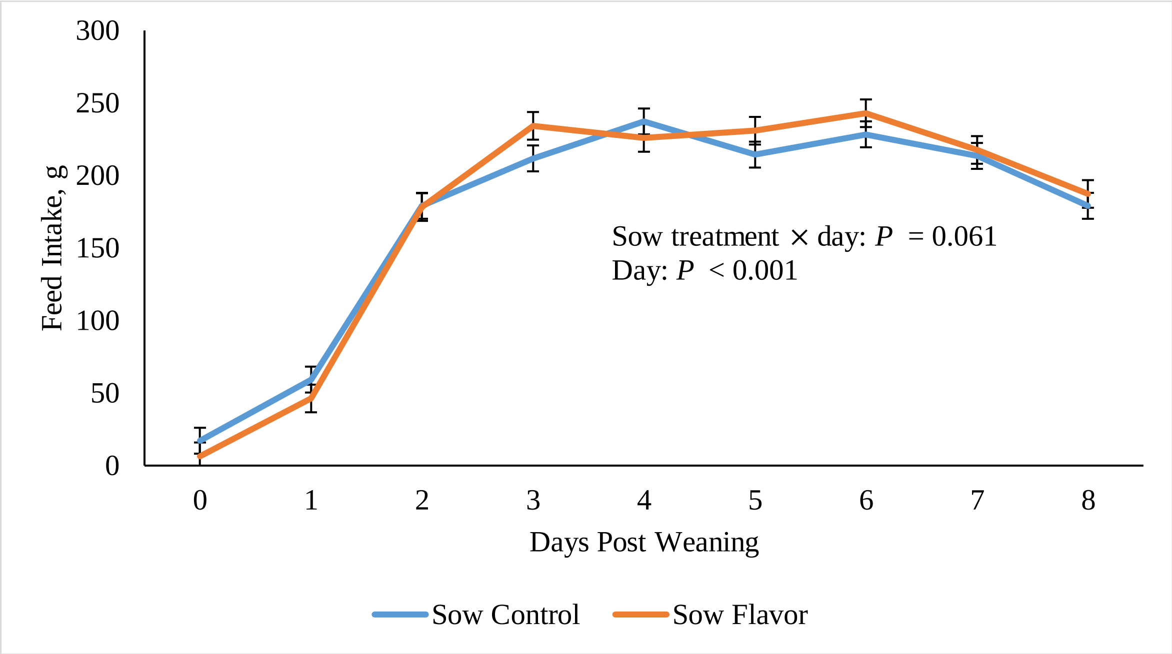

Figure 1-2: Fecal swabs were taken starting ~10 hours post weaning and continued every 12 hours after to define eaters vs non-eaters until all pigs were defined as eaters. Iron oxide was used as an indigestible marker and a red tint on the fecal swab was defined as eaters at each fecal swabbing timepoint was determined.

Figure 1-3 Percentage of pigs defined as eater by time after weaning as influenced by sow or nursery treatment

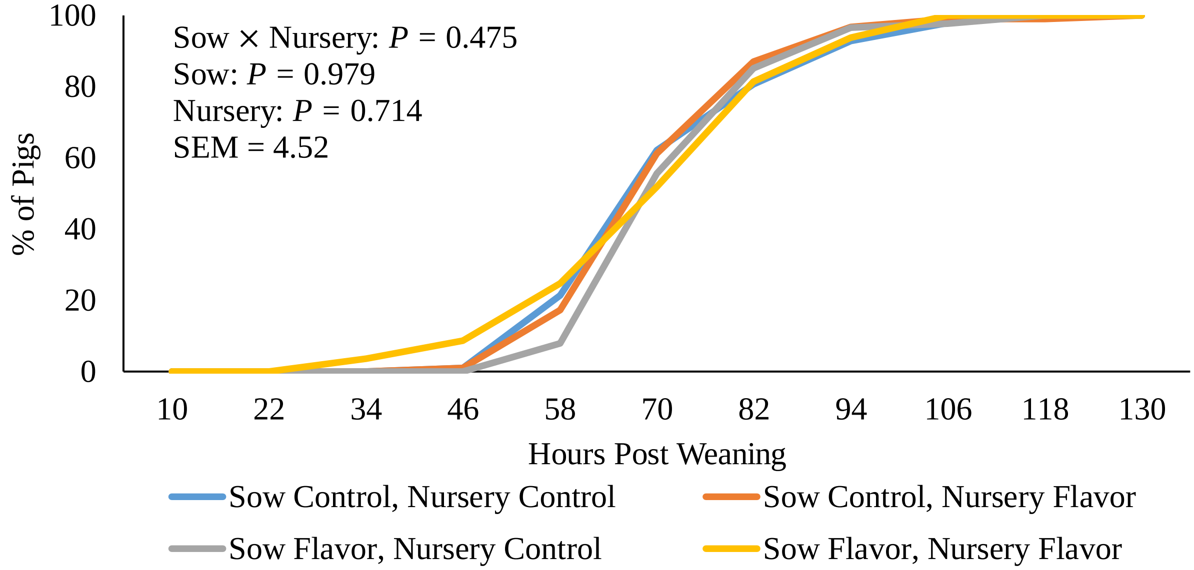

Figure 1-3: Fecal swabs were taken starting ~10 hours post weaning and continued every 12 hours after to define eaters vs non-eaters until all pigs were defined as eaters. Iron oxide was used as an indigestible marker and a red tint on the fecal swab was defined as eaters at each fecal swabbing timepoint was determined.

Figure 1-4 Percentage of piglets that did not gain weight from d 0-3 and d 3-9 by treatment.

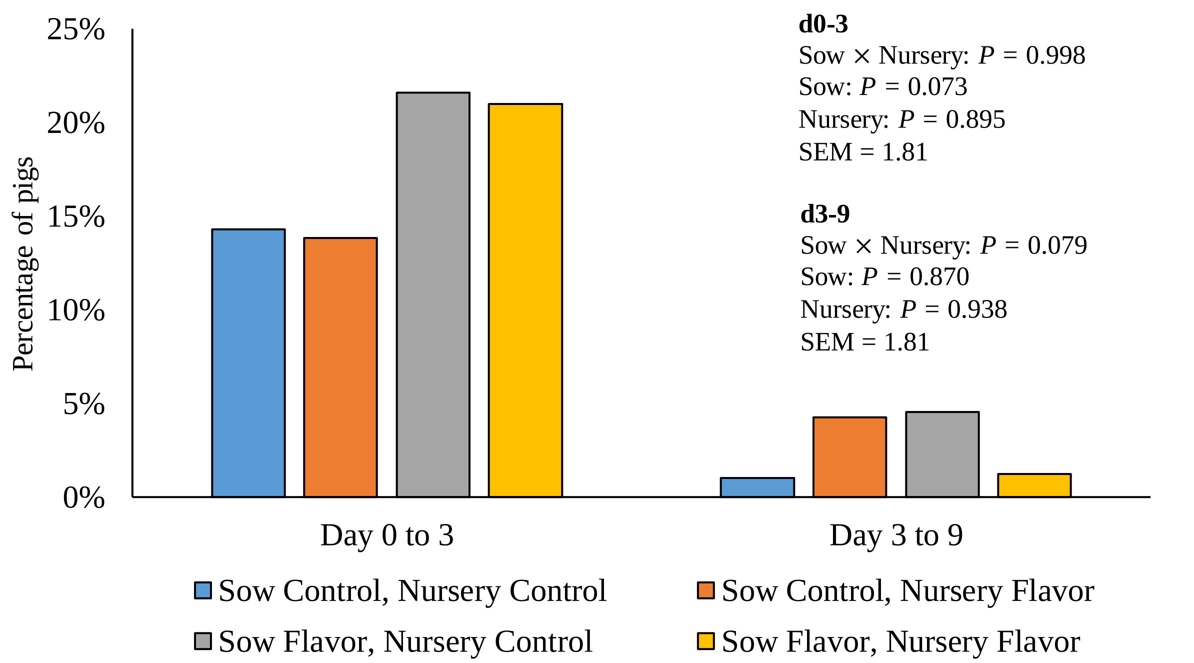

Figure 1-4: Pigs were weighed on d 0, 3, and 9 to determine the percentage of pigs that did not gain weight from d 0-3 and from d 3-9.

Chapter 2 - Comparing tryptophan:lysine ratios in dried distillers grains with solubles-based diets with or without a dried distillers grain with solubles withdrawal strategy on growth, carcass characteristics, carcass fat iodine value and economics of growing-finishing pigs

Abstract

A total of 6,240 finishing pigs (DNA 600 × PIC 1050; initially 22.5 ± 1.00 kg), divided into 2 groups, were used in a 119 or 120 d study comparing increasing Trp:Lys ratio in diets containing dried distillers grains with solubles (DDGS) or a DDGS withdrawal strategy (removing all the DDGS from the last phase before marketing) on growth performance and carcass fat iodine value (IV). Pigs were randomly allotted to 1 of 7 dietary treatments with 30 to 36 pigs per pen and 26 replications per treatment. Diets were fed in 4 phases, approximately 23 to 44, 44 to 71, 71 to 100, and 100 kg to market. Diets included a control corn-soybean meal-based diet (no DDGS) formulated to a 19% standardized ileal digestibility (SID) Trp:Lys ratio, 4 diets with 30% DDGS fed in all four phases and formulated to provide SID Trp:Lys ratios of 16, 19, 22, or 25%, and 2 DDGS withdrawal strategy diets: 19% SID Trp:Lys with 30% DDGS in phase 1 through 3 and then 0% DDGS in phase 4 with either a 19 or 25% Trp:Lys ratio. Overall, body weight (BW), average daily gain (ADG), average daily feed intake (ADFI), and G:F increased (linear, $P < 0.05$) as SID Trp:Lys ratio increased in diets with 30% DDGS fed in all phases. Hot carcass weight (HCW; quadratic, $P = 0.014$), carcass yield (quadratic, $P = 0.012$), and backfat depth (linear, $P = 0.040$) increased with increasing Trp:Lys ratio. Pigs fed the 19% SID Trp:Lys ratio withdrawal strategy had similar ADG and ADFI as those fed the control diet,

the 25% Trp:Lys withdrawal treatment, or the 30% DDGS diets with 25% Trp:Lys ratio throughout the study. Pigs fed the control diet had decreased ($P < 0.05$) carcass fat iodine value (IV) compared to pigs fed DDGS throughout the study, with pigs fed the two DDGS withdrawal strategies intermediate. No differences in revenue per pen or income over feed costs per pen were observed; however, feed cost per kg of gain (quadratic, $P = 0.002$) and feed cost per pig placed (linear, $P = 0.002$) increased, and revenue per pig placed tended to increase ($P = 0.064$) as Trp:Lys ratio increased. In summary, increasing the SID Trp:Lys ratio in diets with 30% DDGS resulted in a linear increase in ADG, ADFI, G:F, and BW but did not influence carcass fat IV, with most of the benefit observed as diets increased from 16 to 19% Trp:Lys. Removing DDGS from the diet in the last period reduced carcass fat IV and increased growth rate during the withdrawal period compared to pigs fed 30% DDGS throughout, indicating value in a withdrawal strategy.

List of Abbreviations:

AA= amino acids

ADFI= average daily feed intake

ADG= average daily gain

BW= body weight

CP= crude protein

DDGS= dried distillers grains with solubles

HCW= hot carcass weight

IV= iodine value

LNNA= large neutral amino acids

NDF= neutral detergent fiber

NE= net energy

SID= standardized ileal digestibility

Introduction

The effect of including DDGS in swine diets has been evaluated in research since the 1940s (Fairbanks et al., 1944; 1945). Dried distillers grains with solubles have a higher fiber content and lower energy digestibility compared to corn (Stein and Shurson, 2009). Meloche et al. (2013) reported that the fat content of DDGS has decreased by 2 to 6% from the reported value of 10% by Stein and Shurson (2009) due to advancements in biorefining technologies and marketing of corn oil. Multiple studies have demonstrated that 30% DDGS can be included in grow-finish diets without negative effects on growth performance (Stein and Shurson, 2009; Rojo et al., 2016); however, the results have been inconsistent. Linneen et al. (2008) observed negative effects on growth performance at DDGS levels as low as 10 to 15% and Jacela et al. (2011) at levels at or above 20%. These differences can be attributed in part due to variations in the nutritional profile of DDGS because of different manufacturing processes (Belyea et al., 2004; Fantini et al., 2021).

Reductions in carcass yield when DDGS are included in diets are commonly observed due to the increased neutral detergent fiber (NDF) content leading to increased gut fill and weight of the intestinal tract (Coble et al., 2018; Soto et al., 2019; Agyekum et al., 2021). Fiber withdrawal strategies are defined as the replacement of high-fiber ingredients in finishing pig diets with low-fiber ingredients for a certain amount of time before marketing with the goal of reducing gut fill and improving carcass yield (Goncalves et al., 2015). Dried distillers grains with solubles withdrawal strategies are commonly implemented in finishing diets to prevent negative impacts on IV, belly firmness, and carcass yield (Xu et al., 2010). Fiber withdrawal strategies have been found to be effective from as short as 5 to 10 days (Asmus et al., 2014, Coble et al., 2018), whereas Gaines et al. (2007) found that a 6-week withdrawal period was needed to recover carcass yield losses due to high fiber diets. However, diets containing DDGS or other sources of fiber are often less expensive than corn-soybean meal diets and consequently, a fiber withdrawal strategy will normally result in more expensive diets being fed.

Tryptophan is an essential amino acid that is the second or third limiting amino acid in swine diets (Guzik et al., 2002). Tryptophan is a precursor for serotonin, which is a neuromodulator that regulates appetite, sleep, and stress (Wolf, 1974; Sève, 1999; Kerr et al., 2002). Dried distillers grains with solubles have lower concentrations of Trp than soybean meal and since the DDGS partially replaces soybean meal in formulations, a higher level of synthetic Trp needs to be included to meet the pig's requirement (Naatjes et al., 2014; Gonçalves et al., 2018). Data has suggested that increasing dietary Trp concentrations to levels greater than the pig's current estimated requirement for growth can improve carcass yield and hot carcass weight (HCW; Nitikanchana, 2013; Salyer et al., 2013). Nitikanchana (2013) observed that increasing SID Trp:Lys from 16.5 to 20% increased carcass yield when DDGs were included in the diet at 20 or 40% all the way to marketing. Salyer et al. (2013) observed a linear improvement in HCW in pigs fed SID Trp:Lys levels from 15 to 19.5%. However, no research has been conducted comparing high SID Trp:Lys ratios in diets with DDGS to a DDGS withdrawal strategy.

If a high SID Trp:Lys ratio can reduce or prevent carcass yield losses from feeding diets containing DDGS, then DDGS could be fed in grow-finish diets up to market, potentially reducing diet costs. Therefore, the objective of this study was to determine the impact of feeding increasing SID Trp:Lys ratios in diets containing DDGS compared to a withdrawal strategy on growth performance, carcass composition, carcass fat IV, and economics in grow-finish pigs. We hypothesized that increasing the Trp:Lys ratio in diets containing 30% DDGS all the way to market would increase carcass yield and HCW to levels equal to pigs fed a DDGS withdrawal and ADFI. We also hypothesized that including 30% DDGS in diets all the way to market would decrease diet costs compared to diets with no DDGS or a DDGS withdrawal strategy.

Materials and Methods

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 finishing facility in Missouri (JBS, Fortuna, MO). The barn was curtain-sided, and tunnel ventilated with a fully slatted concrete floor and deep-pit manure storage. Pens were 7.0 × 3.6 m. Each pen was equipped with a one-sided wet-dry self-feeder to provide a minimum of 38 linear mm of feeder space per pig for ad libitum access to feed and water. Feed was delivered by a feeding system (DryExact Pro, Big Dutchman, Holland, MI, USA) that recorded daily feed additions.

Animals and diets

Two groups of finishing pigs, totaling 6,240 pigs (DNA 600 × PIC 1050; initially 22.5 ± 1.01 kg) were used. Group 1 was on test for 119 d and group 2 for 120 d. Pens of pigs (30 to 36 pigs per pen) were randomly assigned to 1 of 7 dietary treatments in a randomized complete block design with BW serving as the blocking factor resulting in 26 replications per treatment. Dietary treatments were fed in 4 phases from approximately 23 to 44 kg, 44 to 71 kg, 71 to 100, and 100 kg to market (Table 1 and 2). Treatments consisted of: a control, corn-soybean meal-based diet with a 19% SID Trp:Lys ratio fed in phases 1 through 4; 30% DDGS diets with 16% SID Trp:Lys ratio fed in phases 1 through 4; 30% DDGS diets with 19% SID Trp:Lys ratio fed in phases 1 through 4; 30% DDGS diets with 22% SID Trp:Lys ratio fed in phases 1 through 4;

30% DDGS diets with 25% SID Trp:Lys ratio fed in phases 1 through 4, and 2 DDGS withdrawal strategy diets: 19% SID Trp:Lys with 30% DDGS in phase 1 through 3 and then 0% DDGS in phase 4 with either a 19 or 25% Trp:Lys ratios.

All treatment diets were manufactured at a JBS Feed Mill (Centralia, MO, USA). To form the experimental diets, the diets with the lowest and highest Trp:Lys ratio were manufactured first, then blended on farm to create the intermediate Trp:Lys ratio diets. Ingredient nutrient values and their amino acid (AA) SID coefficients were derived from NRC (2012) and diets were formulated to meet or exceed NRC (2012) requirement estimates for growing-finishing pigs for their respective weight ranges except for the diet with a formulated SID Trp:Lys ratio of 16% with 30% DDGS fed in phase 1 through 4.

Pens of pigs were weighed, and feed disappearance was measured every 2 weeks to determine ADG, ADFI, and G:F. Feed samples were collected for each treatment 3 to 5 days before and after a phase change. Pigs were sent to market in 3 marketing events. Four weeks before the end of the experiment, 7 to 8 pigs per pen were marketed; two weeks after the first marketing event, 10 to 12 pigs per pen were marketed, and the remaining pigs were marketed two weeks after the second marketing event. Pigs on the 2 withdrawal treatments were fed the withdrawal diet for 16, 30, or 46 days before marketing events 1, 2, and 3, respectively. For each marketing event, 3 pigs per pen were chosen for fat sample collection, tattooed with the pen number, and loaded separately on trucks with only pigs selected for fat sample collection. Fat samples were collected at the plant from the dorsal loin-butt junction after carcasses sat overnight in the cooler. A circular fat sample with a diameter of approximately 7.5 cm was taken. All fat samples were immediately frozen after collection and later analyzed for carcass fat iodine value (IV) using Near Infrared Spectroscopy. Measurements of hot carcass weight

(HCW), percentage lean, loin depth, and backfat depth were measured on carcasses from all 3 marketing events of the second group of pigs (approximately 2,859 pigs).

For the economic analysis, feed cost, feed cost per kg of gain, revenue per pig, and income over feed costs (IOFC) were calculated on a pen and per pig placed basis. The following ingredient prices were used for the economic analysis: corn = $6.16/bu ($242/ton); soybean meal = $396/ton; DDGS = $220/ton; Biolys (Evonik, Essen, Germany) = $0.66/kg; vitamin-trace mineral premix = $3.37/kg; Methionine hydroxy analogue = $1.57/kg; THR-PRO 80% (CJ Bio, Seoul, South Korea) = $2.18/kg; and L-tryptophan = $9.10/kg. Feed cost per pig placed was calculated by dividing the total feed cost by the number of pigs initially placed per pen. Feed cost per kg of gain was calculated by dividing the feed cost per pig by the overall weight gain per pig. Revenue was obtained by multiplying carcass gain (using the calculated yield from group 2 to calculate carcass gain for group 1 and the calculated yield for group 2 based on live weight and HCW) and using an assumed market value of $1.76/kg. The IOFC was calculated by taking the revenue per pen minus the feed cost per pen.

Statistical analysis

The experimental data were analyzed using the proc GLIMMIX procedure of SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). Pen was the experimental unit for all growth performance data. Response variables were analyzed using a linear mixed model. Treatment was a fixed effect and BW block a random effect. Multiple pairwise comparisons were used to detect differences among all treatments. Additionally, linear and quadratic polynomial contrasts were used to evaluate the effect of increasing SID Trp:Lys ratio (16 to 25% Trp:Lys ratio) in diets containing 30% DDGS up to marketing. Carcass data was analyzed using individual carcass observations and the statistical model incorporated pen as a random intercept to account for the subsampling of multiple observations within each experimental unit. Hot carcass weight was used a covariate for percentage lean, backfat depth, and loin depth. Results were considered significant at $P \leq 0.05$ and a tendency at $P \leq 0.10$.

Results

From d 0 to 70, ADG and ADFI increased (linear, $P < 0.05$) as SID Trp:Lys ratio increased in diets containing 30% DDGS in all 4 phases (Table 5). During this period (d 0 to 70), three treatments were fed the same diet containing 30% DDGS with a 19% SID Trp:Lys ratio. Pigs fed these three treatments had similar ($P > 0.05$) ADG, ADFI, and G:F compared to each other and intermediate ADG between pigs fed the control corn-soybean meal-based diet and those fed the 16% SID Trp:Lys ratio with 30% DDGS. All treatments had a similar ADFI, except for pigs fed 19% SID Trp:Lys ratio withdrawal strategy being greater ($P < 0.05$) than pigs fed the 16% SID Trp:Lys ratio. Pigs fed diets containing 19% SID Trp:Lys ratio with 30% DDGS had a decreased ($P < 0.05$) G:F compared to those fed the control corn-soybean meal-based diet but were similar to all other treatments.

From d 70 to the end of the study (d 119 or 120), increasing the SID Trp:Lys ratio in diets containing 30% DDGS tended (linear, $P = 0.083$) to increase ADG and improved (linear, $P = 0.024$) G:F. Around d 70, the DDGS withdrawal strategy was implemented with pigs switched from 19% SID Trp:Lys with 30% DDGS to diets containing 19 or 25% SID Trp:Lys without DDGS. Pigs fed the 19% Trp:Lys withdrawal diet had greater ($P < 0.05$) ADG and ADFI compared to those fed all other diets except for pigs fed the withdrawal diet with 25% Trp:Lys ratio in phase 4. Pigs fed the withdrawal diet with 25% SID Trp:Lys ratio had improved ($P < 0.05$) ADG compared to pigs fed 30% DDGS diets with 16% or 19% SID Trp:Lys ratio and increased ADFI compared to pigs fed all diets containing 30% DDGS in phase 4. Pigs fed the control diet had a similar (*P* > 0.05) ADG and ADFI when compared to pigs fed all diets containing 30% DDGS in phase 4. No differences in G:F were observed between treatments.

Overall, ADG, ADFI, and G:F increased (linear, *P* < 0.05) with increasing SID Trp:Lys ratio for pigs fed diets with 30% DDGS throughout. For ADG, pigs fed the 19% Trp:Lys ratio withdrawal diet had greater (*P* < 0.05) ADG compared to pigs fed 30% DDGS diets with 16, 19, or 22% Trp:Lys ratios. Pigs fed the 19% SID Trp:Lys withdrawal diet had greater ADFI (*P* < 0.05) than pigs fed the control diet or diets with 30% DDGS throughout with 16, 19, or 22% Trp:Lys ratios. All pigs fed diets containing 30% DDGS had a similar (*P* > 0.05) ADG and ADFI compared to pigs fed the control diet except pigs fed the 16% SID Trp:Lys ratio with 30% DDGS having a lower (*P* < 0.05) ADG. Pigs fed the control corn-soybean meal-based diet had improved (*P* < 0.05) G:F compared to all other treatments except for pigs fed the 19% Trp:Lys ratio withdrawal diet or pigs fed the 30% DDGS diet throughout with 25% Trp:Lys ratio.

Increasing SID Trp:Lys ratio in 30% DDGS diets increased (linear, *P* < 0.001) BW on d 70 and at the end of the study on d 119/120. Pigs fed the 25% SID Trp:Lys ratio withdrawal diet had similar (*P* > 0.05) BW to all other treatments on d 70 and 119/120, except for greater (*P* < 0.05) final BW than pigs fed the 16% Trp:Lys ratio. Pigs fed the 19% Trp:Lys withdrawal diet had greater (*P* < 0.05) BW than pigs fed the 30% DDGS diets containing 16% or 22% Trp:Lys ratio throughout. Pigs fed the control diet had a similar (*P* > 0.05) BW on d 119/120 to pigs on all other treatments except for pigs fed the 16% Trp:Lys ratio (*P* < 0.05).

No differences in BW were observed at the first marketing event of the study. For the second, third, and overall marketing events, BW increased (linear, *P* < 0.001) with increasing Trp:Lys ratio in 30% DDGS diets. Pigs fed the 19% Trp:Lys withdrawal diet had a greater BW (*P* < 0.05) than pigs fed 30% DDGS diets with 16% or 19% Trp:Lys ratio throughout during the

2nd marketing event and pigs fed the 30% DDGS diet with 16% Trp:Lys ratio for the 3rd marketing event. Overall, across all 3 marketing events, pigs fed the withdrawal diet with 19% Trp:Lys ratio had greater ($P < 0.05$) BW at market than pigs fed 30% DDGS diets throughout with 16, 19, or 22% Trp:Lys ratio Pigs fed the control diet had a similar ($P > 0.05$) BW at the marketing event 2 and 3 and overall to all other treatments, except pigs fed diets with a 16% SID Trp:Lys ratio ($P < 0.05$).

As expected, for all time periods, Trp intake per day and intake per kg of gain increased (linear, $P < 0.05$) as SID Trp:Lys ratio increased. From d 0 to 70, Lys intake per day increased (linear, $P = 0.002$) and Lys intake per kg of gain decreased (linear, $P = 0.043$) as Trp increased in the diet. Lysine intake per kg of gain tended to decrease (linear, $P = 0.069$) as the Trp:Lys ratio increased from d 70 to the end of the trial. Overall, Lys intake per day increased (linear, $P = 0.035$) and Lys intake per kg of gain decreased (linear, $P = 0.003$) as Trp:Lys ratio increased.

No differences in carcass characteristics were observed at the first marketing event ($P > 0.05$; Table 6) except for a decrease (quadratic, $P = 0.047$) in carcass yield in pigs fed diets with increasing SID Trp:Lys ratio with 30% DDGS. HCW and loin depth increased (quadratic, $P > 0.05$) in pigs as the SID Trp:Lys ratio increased as well as a tendency for an increase in percentage lean (quadratic, $P = 0.091$) and carcass yield (linear, $P = 0.068$) during marketing event 2. All pigs had a similar ($P > 0.05$) HCW at marketing event 2, except for pigs fed a 16% SID Trp:Lys ratio being lower ($P < 0.05$) than all other treatments.

During marketing event 3, HCW and carcass yield (quadratic, $P < 0.05$) as well as backfat depth (linear, $P = 0.003$) increased in pigs fed diets containing 30% DDGS with an increasing SID Trp:Lys ratio. A tendency for a decrease (quadratic, $P = 0.070$) in percentage lean was also observed as Trp:Lys ratio increased in the diet. Pigs fed diets with a 16% SID Trp:Lys ratio had a lower ($P < 0.05$) HCW than all other treatments. Pigs fed the corn-soybean meal control diet had the highest carcass yield and were significantly greater ($P < 0.05$) than pigs fed the 25% SID Trp:Lys withdrawal diet and SID Trp:Lys of 16 or 22% with 30% DDGS throughout. Percentage lean and loin depth were decreased ($P < 0.05$) for pigs fed 16, 19, or 25% Trp:Lys ratio with 30% DDGS, compared to the control diet. Backfat depth was similar ($P > 0.05$) across all treatments, except pigs fed a 16% SID Trp:Lys ratio being lower ($P < 0.05$) than pigs fed both withdrawal strategies.

Overall, HCW and carcass yield increased (quadratic, $P < 0.05$) in pigs fed diets with an increasing Trp:Lys ratio containing 30% DDGS as well as backfat depth (linear, $P = 0.040$). The greatest increase in HCW was observed as SID Trp:Lys increased from 16 to 19% with a further increase as the ratio increased from 22 to 25%. Overall, pigs fed the 16% Trp:Lys ratio had decreased HCW ($P < 0.05$) compared to pigs fed all other treatments. Pigs fed diets with a 16% SID Trp:Lys ratio had a similar carcass yield to pigs fed the withdrawal strategy with increasing SID Trp:Lys ratio and the 22 or 25% Trp:Lys ratio with 30% DDGS. All other treatments had a greater carcass yield when compared to pigs fed the 16% SID Trp:Lys diets. Pigs fed the withdrawal strategy with a 19% Trp:Lys ratio or 30% DDGS with 22 or 25% Trp:Lys ratio with 30% DDGS had a lower ($P < 0.05$) percentage lean compared to pigs fed the control diet with all other treatments being similar to each other. Pigs fed the control diet had greater overall loin depth ($P < 0.05$) except for pigs fed the withdrawal strategy treatment with increasing SID Trp:Lys in phase 4 or pigs fed the 22% SID Trp:Lys ratio.

When comparing carcass fat IV, pigs fed diets that contained 30% DDGS throughout the study had greater ($P < 0.05$) IV for all 3 marketing events, as well as overall, than the control or DDGS withdrawal treatments (Table 7). Pigs fed either of the two withdrawal treatments, which contained 30% DDGS from phase 1 to 3 and then 0% in phase 4, had greater ($P < 0.05$) IV than pigs fed the control diet. There was a tendency ($P = 0.057$) for a linear increase in IV for the 3rd marketing event as the Trp:Lys ratio increased.

As the Trp:Lys ratio increased in diets with 30% DDGS, revenue per pen tended to increase (quadratic, $P = 0.071$; Table 8). Pigs fed the control corn-soybean meal-based diet had the greatest numeric feed cost per pen, and pigs fed the 16% Trp:Lys ratio had the lowest feed cost per pen with all other treatments intermediate. Income over feed cost per pen increased (quadratic, $P = 0.012$) as the Trp:Lys ratio increased in diets with 30% DDGS. As the SID Trp:Lys ratio increased feed cost per kg of gain also increased (quadratic, $P = 0.002$). Pigs fed the control diet had greater ($P < 0.05$) feed cost per kg of gain compared to pigs fed diets with a 19% SID Trp:Lys DDGS withdrawal strategy and 30% DDGS with 19 or 22% SID Trp:Lys ratios. Revenue per pig placed increased (linear, $P = 0.043$) as the Trp:Lys ratio increased. Pigs fed the standard corn-soy based diet and the withdrawal strategy diet with a 19% Trp:Lys ratio had a greater revenue per pig placed compared to pigs fed a deficient level of Trp, 16%. Feed cost per kg of gain increased (linear, $P = 0.002$) as SID Trp:Lys ratio increased. Pigs fed the control diet and 30% DDGS diet with 25% Trp:Lys ratio fed throughout had greater ($P < 0.05$) feed cost per pig placed compared to pigs fed 30% DDGS with 16% Trp:Lys ratio, with all other treatments intermediate. An increase (quadratic, $P = 0.040$) in IOFC per pig placed was observed as the SID Trp:Lys ratio increased in diets with 30% DDGS.

Discussion

Research has suggested that increasing the Trp:Lys ratio in diets containing DDGS can reduce the negative impacts on growth performance and carcass characteristics commonly seen when feeding diets with DDGS up to market (Salyer et al., 2013; Nitikanchana, 2013; Clizer, 2021). Like our study, Clizer (2021) observed linear increases in ADG, ADFI, and final BW as the SID Trp:Lys ratio increased from 15 to 25% in diets with 40% DDGS. Salyer et al. (2013) also observed a linear improvement in ADG, ADFI, and final BW as the SID Trp:Lys ratio increased from 14 to 18% of Lys in diets containing 30% DDGS. However, Nitikanchana (2013) reported that pigs fed a standard corn-soy-based diet had better growth performance compared to pigs fed diets with an increasing Trp:Lys ratio from 15 to 21% of Lys in diets with 30% DDGS. This contrasts the findings of this study where pigs fed a standard corn-soybean meal-based diet had similar performance to pigs fed diets with 30% DDGS and 19, 22, or 25% Trp:Lys ratios. In a second experiment, Nitikanchana (2013) found that increasing the SID Trp:Lys ratio from 15 to 21% of Lys in diets with 30% DDGS had no effect on growth performance. However, none of the other reported studies compared increasing SID Trp:Lys ratios to a DDGS withdrawal strategy.

When evaluating the SID Trp:Lys ratio in standard corn-soy based diets with no DDGS, other research has reported improvements in ADG, ADFI, and G:F as the ratio is increased. Quant et al. (2012) found a linear improvement in ADG, ADFI, and G:F as Trp increased from 12.8 to 17.9% of Lys and Liu et al. (2019) found a quadratic increase in ADG, ADFI, and G:F as the SID Trp:Lys ratio increased from 15 to 25%. In another study, Ma et al. (2015) found a quadratic improvement in ADG and G:F as Trp:Lys ratio increased from 12 to 24%, respectively.

The improvements in feed intake and growth performance when the Trp:Lys ratio was increased could be explained by the increase in the Trp:LNNA ratio. Large neutral amino acids (LNNA), including Val, Ile, Leu, Thr, Tyr, and Phe, compete with Trp for transport across the blood brain barrier because they share a common transport mechanism (Leathwood, 1987; Henry et al., 1992; Pardridge, 1998). Furthermore, DDGS are high in Leu, Met, and Thr, which have been found to have a negative effect on Trp uptake in the brain (Sainio et al., 1996; Sève, 1999; Kerr et al., 2002). The use of DDGS in swine diets increases the large neutral amino acids concentration because of an increase in dietary crude protein (CP) from corn (NRC, 2012). Lui et al. (2019) suggested that the Trp requirement in diets with DDGS is greater due to the greater LNNA concentration. Corn proteins are also generally low in Trp (Stein, 2007) which creates metabolic problems with the Trp:LNNA ratio and Trp uptake in the brain. Salyer et al. (2013) reported that Trp to LNAA ratio of 3.1% or below can negatively affect growth performance. Tryptophan has been found to have a positive effect on feed intake (Russell et al., 1983; Sève et al., 1991; Batterham et al., 1994). This impact is suggested to be a result of Trp effects on the appetite hormones, serotonin, insulin, and ghrelin (Le Floc'h and Sève, 2007; Zhang et al., 2007). Tryptophan is a precursor for serotonin, which has been shown to play a role in appetite regulation (Wolf, 1974; Sève, 1999), which could explain the linear increase in ADFI as the Trp level increased in our study. Henry et al. (1996) found that excess protein in relation to Trp can cause a decrease in feed intake and growth performance due to a decrease in serotonin production. The results indicate that as the level of LNAA in the diet increases, the optimum level of dietary Trp should also be increased.

Salyer et al. (2013) and Clizer (2021) observed increases in HCW as the Trp:Lys ratio increased, similar to the findings of this study. In another study, Nitikanchana (2013) observed a tendency for an increase in carcass yield as the Trp:Lys ratio increased. However, only two levels of Trp, 16.5% or 20%, were used with 0, 20, or 40% DDGS. The increase in carcass yield observed by increasing the Trp level in diets in some studies could be explained by the finding of Ponter et al. (1994) who reported that increasing the Trp level increased gastric stomach emptying, providing a potential explanation for improvements in carcass yield. In our study a quadratic effect was observed for carcass yield with the greatest improvement in yield between pigs fed diets with 16% SID Trp:Lys to pigs fed a 19% ratio with a slight decrease going up to 22% or 25% SID Trp:Lys ratio.

Dried distillers grains with solubles withdrawal strategies can be used to improve growth or carcass performance. Lerner et al. (2020b) observed an increase in ADG, ADFI, and G:F as the withdrawal period increased from 0 to 76 days. One experiment by Lerner et al. (2020a) observed that as the length of the fiber withdrawal strategy increased from 0 to 25 days, ADFI increased, but in a second experiment no differences in ADFI were found as the withdrawal period increased from 0 to 35 days. In another study, pigs fed a diet containing 30% DDGS had a lower ADFI compared to pigs fed 0% DDGS (Coble et al., 2017). This is in contrast to the finding of our study, where pigs fed diets containing 30% DDGS had a similar overall ADFI to pigs fed the corn-soy-based diets. However, pigs fed the withdrawal strategy diet with a 19% SID Trp:Lys ratio had a higher ADG and ADFI compared to pigs fed diets with 30% DDGS with 16, 19, or 22% SID Trp:Lys ratio. Other studies have observed no differences in ADFI, ADG, or G:F in pigs placed on varying lengths of a fiber withdrawal strategy vs no fiber withdrawal (Coble et al., 2018; Lerner et al., 2020a). Rojo et al. (2016) found that DDGS can be included in the diet at 30% without negative effects on growth performance. The results of our study illustrate the positive benefits of a DDGS withdrawal strategy. The results of this study also illustrate the importance of increasing Trp levels in diets containing 30% DDGS for both growth performance and carcass characteristics.

A regression analysis by Soto et al. (2019) found that increasing the withdrawal period increased carcass yield. However, the response is dependent on NDF level. Coble et al. (2017)

and Lerner et al. (2020a) observed a linear reduction in yield as the fiber withdrawal period decreased with pigs fed diets with DDGS up to market having the lowest carcass yield. However, other studies observed no differences in carcass yield regardless of the DDGS level in the diet before market (Coble et al., 2018). The current study observed no differences in carcass yield when comparing pigs fed the corn-soybean meal-based diet and withdrawal diets compared to most diets with 30% DDGS fed until marketing. However, pigs fed the 16% SID Trp:Lys ratio had a lower carcass yield compared to pigs fed the corn-soybean meal-based diet and withdrawal strategy with a 19% SID Trp:Lys ratio, indicating the importance of feeding adequate Trp levels when including DDGS in the diet. Differences in yield were not observed between treatments until the third marketing event when pigs on the withdrawal strategy diets had been consuming no DDGS for 46 days. These results indicate that pigs can be fed 30% DDGS up to market without seeing negative effects on carcass yield when Trp levels are 19% of Lys or higher. This is in contrast with the findings of Rojo et al. (2016) who found a linear reduction in carcass yield as the DDGS level increased from 0 to 30%.

High-fiber diets have been found to have negative impacts on HCW. Pigs fed a high DDGS diet up to market had a 5 kg lower HCW compared to pigs placed on a fiber withdrawal strategy 76 days before market (Lerner et al., 2020b). In another study, pigs fed a high-fiber diet throughout the grow-finish period had a 4.3 kg lighter HCW compared to pigs fed the low-fiber corn soy-based diet (Coble et al., 2018). In this study, pigs fed a 19% SID Trp:Lys ratio with 30% DDGS had roughly a 1 kg reduction in HCW weight compared to pigs fed the standard corn soy-based diet or pigs fed the 19% SID Trp:Lys fiber withdrawal strategy. A quadratic improvement in HCW was observed as the SID Trp:Lys ratio increased, with pigs fed the highest SID Trp:Lys ratio, 25%, having a 5 kg greater HCW compared to pigs fed diets with a 16% SID

Trp:Lys ratio. The biggest improvement in HCW was observed when increasing the Trp:Lys ratio from 16% to 19% Trp:Lys ratio.

Multiple studies have demonstrated the effects of a DDGS withdrawal period and high vs low DDGS levels on carcass fat IV (Nemechek et al., 2015; Coble et al., 2018; Lerner et al., 2020a). Iodine value is a way for packers to determine the quality of pork fat by measuring the unsaturated fatty acid content in fat (Nemechek et al., 2015) with a higher IV indicating more unsaturated fatty acid concentrations. Nemechek et al. (2015), Coble et al. (2018), and Lerner et al. (2020a) all observed an increase in carcass IV as the fiber withdrawal period was shortened or the fiber level was increased in the diet. The increase in IV due to the inclusion of DDGS is because of the high unsaturated fatty acid content in DDGS (NRC, 2012). This agrees with the results of the current study. The decrease in IV value in pigs fed the standard corn-soybean meal-based diet compared to the withdrawal strategy diet and diets with 30% DDGS throughout can be attributed to the decrease in the unsaturated fatty acid content of the diet. In the present study, increasing the SID Trp:Lys ratio in diets with 30% DDGS did not have any effect on carcass IV.

Conclusion

In summary, ADG, ADFI, G:F, and BW improved linearly as SID Trp:Lys ratio increased from 16 to 25% in diets containing 30% DDGS fed all the way to marketing with the greatest improvement going from deficient levels,16% Trp:Lys ratio, to adequate levels, 19% Trp:Lys ratio. Pigs fed either of the two DDGS withdrawal strategies had similar ADG and ADFI compared to pigs fed diets with a 25% Trp:Lys ratio with 30% DDGS throughout. Furthermore, HCW quadratically increased as the SID Trp:Lys increased in diets containing 30% DDGS. Pigs fed the control diet or the 19% SID Trp:Lys ratio withdrawal strategy had a greater carcass yield than pigs fed the 16% SID Trp:Lys ratio but were statistically similar to all other pigs fed diets with 30% DDGS throughout. Pigs fed the diet without DDGS had the lowest carcass fat IV, and pigs fed a DDGS-withdrawal strategy had a lower IV than pigs fed diets containing 30% DDGS throughout the entire study. These results demonstrate the value of withdrawing DDGS in the diet before market on carcass IV and the importance of feeding adequate Trp, above a 16% Trp:Lys ratio, in diets containing DDGS. Pigs fed the highest level of Trp, 25% Trp:Lys ratio, with 30% DDGS had similar overall growth performance to pigs fed the withdrawal strategies and the control corn soybean meal-based diet. However, feeding a high SID Trp:Lys ratio alone does not replace a DDGS withdrawal strategy when considering IV. The results also indicate different dietary DDGS and SID Trp:Lys ratio strategies can be used depending on ingredient and market prices.

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Table 2-1 Composition of phase 1 and 2 diets (as-fed basis)[1]

	Phase 1			Phase 2		
DDGS, %[2]:	0	30		0	30	
SID Trp:Lys, %[2]:	19	16[3]	25	19	16	25
Ingredients, %						
Corn	69.79	50.72	50.66	79.28	56.73	56.69
Soybean meal	26.30	13.30	13.31	17.06	7.82	7.83
DDGS[4], 5.5% oil	---	30.00	30.00	---	30.00	30.00
Choice white grease	---	2.14	2.10	---	2.24	2.20
Calcium carbonate	1.40	1.26	1.26	1.26	1.17	1.17
Monocalcium P (21% P)	0.63	0.20	0.20	0.47	---	---
Salt	0.54	0.41	0.41	0.55	0.42	0.42
L-Lys[5]	0.87	1.55	1.55	0.94	1.34	1.34
Methionine hydroxy analog	0.14	0.08	0.08	0.10	0.01	0.01
L-Thr[6]	0.15	0.17	0.17	0.15	0.10	0.10
L-Trp	0.02	0.02	0.12	0.04	0.02	0.10
Mineral-vitamin premix[7]	0.15	0.15	0.15	0.15	0.15	0.15
Calculated analysis						
Standardized ileal digestibility amino acids, %						
Lys	1.11	1.11	1.11	0.91	0.91	0.91
His:Lys	40	38	38	39	41	41
Ile:Lys	60	56	56	57	59	59
Leu:Lys	129	148	148	134	168	168
Met:Lys	34	32	32	33	30	30
Met & Cys:Lys	57	57	57	57	58	58
Thr:Lys	62	62	62	62	62	62
Trp:Lys	19	16	25	19	16	25
Val:Lys	67	67	67	65	72	72
Total Lys, %	1.24	1.29	1.29	1.01	1.07	1.07
NE, kcal/kg	2,533	2,533	2,533	2,560	2,560	2,560
SID Lys:NE, g/Mcal	4.38	4.38	4.38	3.54	3.54	3.54
CP, %	18.54	19.71	19.80	15.06	17.51	17.57
Ca, %	0.75	0.62	0.62	0.64	0.53	0.53
P, %	0.51	0.49	0.49	0.43	0.42	0.42
STTD P, %	0.39	0.39	0.39	0.34	0.34	0.34

[1]Phases 1 and 2 were fed from 23 to 44 and 44 to 71 kg, respectively.

[2]While the formulation strategy was the same between groups, minor differences in feed formulas existed between groups based on differences in loading values of ingredients.

[3]The two diets containing 30% DDGS with either 16 or 25% SID Trp:Lys ratio were blended on farm to form the 19 and 22% SID Trp:Lys ratio diets.

[4]Dried distillers grains with solubles

[5]Biolys liquid 32.5% (Evonik, Essen, Germany)

[6]THR-PRO 80% (CJ Bio, Seoul, South Korea)

[7]Minerals and vitamins provided per kg of premix: 800 g STTP P, 148,325 FTU phytase, 0.02 g Na, 10 g S, 5,873 g Zn, 7,341 g Fe, 1,867 g Mn, 1,000 g Cu, 198 mg Se, 2,204,634 IU vitamin A, 661,390 IU vitamin D, 19,595 IU vitamin E, 1,323 mg vitamin K, 13 mg vitamin B12, 19,482 mg Niacin, 11,023 pantothenic acid, 3,307 mg riboflavin, and 198 mg iodine.

Table 2-2 Composition of phase 3 and 4 diets (as-fed basis)[1]

	Phase 3			Phase 4			
DDGS, %[2]:	0	30		0		30	
SID Trp:Lys, %[2]:	19	16[3]	25	19	25	16	25
Ingredients, %							
Corn	85.03	58.11	58.07	85.25	85.20	57.46	57.43
Soybean meal	11.74	6.65	6.65	11.67	11.68	7.64	7.64
DDGS[4], 5.5% oil	---	30.00	30.00	---	---	30.00	30.00
Choice white grease	---	2.52	2.48	---	---	2.48	2.45
Calcium carbonate	1.14	1.16	1.16	1.17	1.17	1.17	1.17
Monocalcium P (21% P)	0.26	---	---	0.34	0.34	---	---
Salt	0.56	0.42	0.42	0.56	0.56	0.42	0.42
L-Lys[5]	0.89	0.97	0.97	0.73	0.73	0.73	0.73
Methionine hydroxy analog	0.06	---	---	0.03	0.03	---	---
L-Thr[6]	0.14	0.02	0.02	0.12	0.12	---	---
L-Trp	0.04	0.02	0.07	0.03	0.07	---	0.05
Mineral-vitamin premix[7]	0.15	0.15	0.15	0.10	0.10	0.10	0.10
Calculated analysis							
Standardized ileal digestibility amino acids, %							
Lys	0.76	0.76	0.76	0.70	0.71	0.70	0.70
His:Lys	40	48	48	43	43	53	53
Ile:Lys	56	67	67	60	60	75	75
Leu:Lys	143	197	197	154	154	216	216
Met:Lys	32	34	34	31	31	38	38
Met & Cys:Lys	58	67	67	59	59	73	73
Thr:Lys	64	64	64	66	66	68	68
Trp:Lys	19	16	25	19	25	16	25
Val:Lys	66	84	83	71	71	92	92
Total Lys, %	0.85	0.92	0.92	0.80	0.80	0.87	0.87
NE, kcal/kg	2,579	2,579	2,579	2,579	2,579	2,579	2,579
SID Lys:NE, g/Mcal	2.94	2.94	2.94	2.73	2.73	2.73	2.73
CP, %	13.02	16.83	16.89	12.91	12.95	17.11	17.15
Ca, %	0.55	0.52	0.52	0.57	0.57	0.53	0.53
P, %	0.36	0.42	0.42	0.38	0.38	0.42	0.42
STTD P, %	0.29	0.34	0.34	0.26	0.26	0.30	0.30

[1]Phases 3 and 4 were fed from 71 to 100 and 100 kg to market, respectively.

[2]While the formulation strategy was the same between groups, minor differences in feed formulas existed between groups based on differences in loading values of ingredients.

[3]The two diets containing 30% DDGS with either 16 or 25% SID Trp:Lys ratio were blended on farm to form the 19 and 22% SID Trp:Lys ratio diets.

[4]Dried distillers grains with solubles

[5]Biolys liquid 32.5% (Evonik, Essen, Germany)

[6]THR-PRO 80% (CJ Bio, Seoul, South Korea)

[7]Minerals and vitamins provided per kg of premix: 800 g STTP P, 148,325 FTU phytase, 0.02 g Na, 10 g S, 5,873 g Zn, 7,341 g Fe, 1,867 g Mn, 1,000 g Cu, 198 mg Se, 2,204,634 IU vitamin A, 661,390 IU vitamin D, 19,595 IU vitamin E, 1,323 mg vitamin K, 13 mg vitamin B12, 19,482 mg Niacin, 11,023 pantothenic acid, 3,307 mg riboflavin, and 198 mg iodine.

Table 2-3 Chemical analysis for Phase 1 and 2 diets[1]

	Phase 1			Phase 2		
DDGS, %[2]:	0	30		0	30	
SID Trp:Lys, %[2]:	19	16[3]	25	19	16	25
Amino acid, %						
Lysine[4]	1.33	1.50	1.66	0.99	1.06	1.08
Histidine	0.47	0.47	0.58	0.38	0.42	0.42
Isoleucine	0.70	0.70	0.86	0.55	0.58	0.61
Leucine	1.50	1.68	1.95	1.24	1.51	1.55
Methionine	0.28	0.33	0.38	0.23	0.29	0.30
Threonine	0.79	0.78	0.95	0.59	0.62	0.64
Tryptophan	0.27	0.21	0.35	0.18	0.18	0.24
Valine	0.84	0.84	0.99	0.65	0.72	0.75
Free Lysine	0.44	0.74	0.73	0.33	0.50	0.62
Free Threonine	0.13	0.16	0.14	0.10	0.09	0.11
Free Tryptophan	0.05	0.02	0.10	0.02	0.04	0.10

[1]Phases 1 and 2 were fed from 23 to 44 and 44 to 71 kg, respectively.

[2]While the formulation strategy was the same between groups, minor differences in feed formulas existed between groups based on differences in loading values of ingredients.

[3]The two diets containing 30% DDGS with either 16 or 25% SID Trp:Lys ratio were blended on farm to form the 19 and 22% SID Trp:Lys ratio diets.

[4]Diet samples were submitted to Ajinomoto (Eddyville, IA, USA) for analysis.

Table 2-4 Chemical analysis of Phases 3 and 4 diets[1]

	Phase 3			Phase 4			
DDGS, %[2]:	0	30		0		30	
SID Trp:Lys, %[2]:	19	16[3]	25	19	25	16	25
Amino acid, %							
Lysine[4]	0.86	0.87	0.91	0.75	0.74	0.81	0.80
Histidine	0.33	0.40	0.40	0.33	0.33	0.40	0.40
Isoleucine,	0.48	0.56	0.56	0.47	0.47	0.52	0.53
Leucine	1.12	1.49	1.48	1.11	1.11	1.43	1.44
Methionine	0.20	0.28	0.28	0.20	0.20	0.28	0.28
Threonine	0.54	0.56	0.57	0.50	0.51	0.54	0.54
Tryptophan	0.17	0.15	0.20	0.15	0.19	0.15	0.19
Valine	0.57	0.69	0.70	0.55	0.55	0.67	0.67
Free Lysine	0.34	0.37	0.39	0.19	0.21	0.24	0.26
Free Threonine	0.16	0.05	0.05	0.12	0.16	0.05	0.05
Free Tryptophan	0.04	0.01	0.07	0.05	0.08	0.01	0.05

[1]Phases 3 and 4 were fed from 71 to 100 and 100 kg to market, respectively.

[2]While the formulation strategy was the same between groups, minor differences in feed formulas existed between groups based on differences in loading values of ingredients.

[3]The two diets containing 30% DDGS with either 16 or 25% SID Trp:Lys ratio were blended on farm to form the 19 and 22% SID Trp:Lys ratio diets.

[4]Diet samples were submitted to Ajinomoto (Eddyville, IA, USA) for analysis.

Table 2-5 Effects of Trp:Lys ratios and DDGS withdrawal strategies on growth, Trp intake and removals/mortality of growing finishing pigs[1]

DDGS[2]:	0	30-0% withdrawal		30% throughout					*P* =		
SID Trp:Lys, %[2]:	19	19	19-25	16	19	22	25	SEM	Treatment	Linear[3]	Quadratic[3]
Item											
BW, kg											
d 0	22.5	22.5	22.5	22.5	22.5	22.5	22.5	0.20	0.999	0.972	0.787
d 70	96.2[a]	95.8[a]	94.6[ab]	93.5[b]	95.0[ab]	94.9[ab]	96.0[a]	0.61	< 0.001	< 0.001	0.591
d 119/120	134.7[ab]	136.4[a]	134.4[ab]	129.5[c]	133.6[ab]	132.7[bc]	134.9[ab]	1.10	< 0.001	< 0.001	0.252
Market weight, kg											
1st Cut (d 91/92)[4]	131.6	131.5	130.0	131.2	130.8	130.6	130.7	0.81	0.728	0.576	0.729
2nd Cut (d 105)[5]	136.3[ab]	137.6[a]	135.6[ab]	132.7[c]	134.3[bc]	135.3[abc]	136.1[ab]	0.93	< 0.001	< 0.001	0.524
3rd Cut (d 119/120)[6]	134.7[a]	136.4[a]	134.4[a]	129.5[b]	133.6[a]	133.1[a]	134.8[a]	1.16	< 0.001	< 0.001	0.146
Overall[7,8]	134.7[ab]	135.8[a]	133.9[ab]	131.2[c]	133.3[bc]	133.4[bc]	134.3[ab]	0.66	< 0.001	< 0.001	0.309
d 0 to 70											
ADG, kg	1.05[a]	1.04[ab]	1.02[bc]	1.01[c]	1.03[abc]	1.03[abc]	1.04[ab]	0.01	< 0.001	< 0.001	0.489
ADFI, kg	2.54[ab]	2.56[a]	2.53[ab]	2.49[b]	2.54[ab]	2.53[ab]	2.56[a]	0.02	0.016	0.002	0.571
G:F	0.413[b]	0.407[a]	0.404[a]	0.403[a]	0.405[a]	0.405[a]	0.406[a]	< 0.01	< 0.001	0.113	0.801
Trp intake, g/d	4.17[c]	4.19[c]	4.14[c]	3.44[d]	4.16[c]	4.80[b]	5.54[a]	0.03	< 0.001	< 0.001	0.590
Trp intake, g/kg gain	4.15[d]	4.19[cd]	4.23[c]	3.56[e]	4.21[cd]	4.87[b]	5.54[a]	0.03	< 0.001	< 0.001	0.395
Lys intake, g/d	22.79[ab]	22.93[ab]	22.70[ab]	22.37[b]	22.77[ab]	22.70[ab]	22.98[ab]	0.24	0.018	0.002	0.602
Lys intake, g/kg gain	22.71[b]	23.01[ab]	23.19[a]	23.22[a]	23.07[a]	23.09[a]	23.00[ab]	0.33	< 0.001	0.043	0.664
d 70 to 119/120											
ADG, kg	1.03[bc]	1.07[a]	1.06[ab]	1.01[c]	1.01[c]	1.02[bc]	1.03[bc]	0.01	< 0.001	0.083	0.806
ADFI, kg	3.41[bc]	3.55[a]	3.49[ab]	3.39[c]	3.40[c]	3.39[c]	3.40[c]	0.03	< 0.001	0.696	0.889
G:F	0.304	0.303	0.303	0.299	0.298	0.302	0.303	0.02	0.078	0.024	0.496
Trp intake, g/d	4.96[d]	5.16[c]	6.44[a]	4.15[e]	4.95[d]	5.70[b]	6.48[a]	0.09	< 0.001	< 0.001	0.693
Trp intake, g/kg gain	5.01[d]	5.02[d]	6.37[a]	4.28[e]	5.11[d]	5.84[c]	6.60[a]	0.14	< 0.001	< 0.001	0.336
Lys intake, g/d	24.44[bc]	25.41[a]	25.04[ab]	24.28[c]	24.34[c]	24.20[c]	24.21[c]	0.79	< 0.001	0.5n92	0.857
Lys intake, g/kg gain	24.73[ab]	24.76[b]	24.82[ab]	25.03[ab]	25.22[a]	24.87[ab]	24.78[ab]	0.97	0.109	0.069	0.292
Overall											
ADG, kg	1.04[ab]	1.05[a]	1.03[ab]	1.01[c]	1.02[bc]	1.02[bc]	1.04[ab]	0.01	< 0.001	0.001	0.699
ADFI, kg	2.84[bc]	2.90[a]	2.86[ab]	2.80[c]	2.84[bc]	2.83[bc]	2.85[abc]	0.02	< 0.001	0.020	0.655
G:F	0.367[b]	0.363[ab]	0.361[a]	0.360[a]	0.361[a]	0.363[a]	0.364[ab]	< 0.01	< 0.001	0.005	0.922

Trp intake, g/d	4.44[de]	4.52[d]	4.93[c]	3.69[f]	4.43[e]	5.11[b]	5.87[a]	0.04	< 0.001	< 0.001	0.818
Trp intake, g/kg gain	4.43[e]	4.47[de]	4.97[c]	3.80[f]	4.50[d]	5.19[b]	5.89[a]	0.03	< 0.001	< 0.001	0.922
Lys intake, g/d	23.37[abc]	23.80[a]	23.51[ab]	23.04[c]	23.33[bc]	23.23[bc]	23.42[abc]	0.21	< 0.001	0.035	0.636
Lys intake, g/kg gain	23.34[b]	23.55[ab]	23.67[a]	23.78[a]	23.71[a]	23.59[ab]	23.50[ab]	0.15	< 0.001	0.003	0.888
Removals, %											
Removals, %	2.4	3.0	3.9	2.9	2.9	3.4	3.2	0.73	0.629	0.579	0.827
Mortality, %	1.6	1.5	0.9	1.3	0.8	1.1	0.7	0.42	0.480	0.293	0.948
Total removals, %	3.9	4.5	4.8	4.2	3.7	4.6	3.9	0.81	0.889	0.971	0.929

[1]A total of 6,240 pigs (initially 22.5 kg) were used with 30-36 pigs per pen and 26 replications per treatment.

[2]Pigs were either fed diets containing 0% DDGS with 19% standardized ileal digestible (SID) Trp:Lys ratio from day 0 to 119/120, 30% DDGS from d 0 to 70 and 0% DDGS from d 70 to 119/120 with SID Trp:Lys ratios of 19% from d 0 to 119/120 or 19% from d 0 to 70 and 25% SID Trp:Lys from d 70 to 119/120, or fed 30% DDGS from d 0 to 119/120 with levels of SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[3]Linear and quadratic contrasts included treatments containing 30% DDGS and a SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[4]6-9 pigs per pen were marketed on d 84/92.

[5]10-12 pigs per pen were marketed on d 98/105.

[6]9-15 pigs per pen were marketed on d 119/120.

[7]Weighted average of pig marketed on d 84/92, 98/105 and 119/120 by pen.

[8]The DDGS withdrawal diet was fed for 16, 30, or 46 days before marketing event 1, 2, or 3 respectively.

[a,b,c,d] Means in the same row that do not have a common superscript differ ($P < 0.05$).

Table 2-6 Effects of Trp:Lys ratios and DDGS withdrawal strategies on carcass characteristics of growing finishing pigs[1]

DDGS, %[2]:	0	30-0 withdrawal		30 throughout					*P* =		
SID Trp:Lys, %[2]:	19	19	19-25	16	19	22	25	SEM	Treatment	Linear[3]	Quadratic[3]
Item											
Cut 1											
HCW, kg	93.5	92.3	92.2	93.4	93.8	93.1	93.3	0.90	0.786	0.764	0.895
Carcass yield, %	71.4	71.2	70.9	70.8	71.1	71.1	70.3	0.74	0.135	0.205	0.047
Lean, %[4]	53.1	52.4	52.8	52.5	52.5	52.6	52.6	0.20	0.241	0.574	0.876
Loin depth, in.[4]	6.20	5.97	6.11	6.03	6.06	6.09	6.08	0.07	0.448	0.549	0.758
Back fat depth, cm.[4]	1.94	2.02	1.99	2.01	2.02	2.04	2.02	0.03	0.443	0.801	0.533
Cut 2											
HCW, kg	95.7[a]	96.6[a]	94.7[a]	90.8[b]	94.3[a]	96.3[a]	96.7[a]	0.85	< 0.001	< 0.001	0.022
Carcass yield, %	72.0	71.9	71.4	71.2	71.6	71.9	71.7	0.75	0.088	0.068	0.199
Lean, %[4]	52.8	52.4	52.7	52.5	53.0	52.7	52.7	0.18	0.155	0.706	0.091
Loin depth, cm.[4]	6.00	5.90	5.98	5.81	6.02	5.98	5.95	0.06	0.110	0.138	0.029
Back fat depth cm.[4]	1.88	1.95	1.90	1.88	1.83	1.91	1.89	0.01	0.323	0.509	0.639
Cut 3											
HCW, kg	100.4[a]	101.2[a]	98.8[a]	93.3[b]	99.3[a]	98.9[a]	101.1[a]	1.06	< 0.001	< 0.001	0.024
Carcass yield, %	73.0[a]	72.6[ab]	72.1[bc]	71.6[c]	72.7[ab]	72.0[bc]	72.2[abc]	0.01	< 0.001	0.177	0.043
Lean, %[4]	53.2[a]	52.6[ab]	52.5[b]	53.1[ab]	52.5[b]	52.6[ab]	52.4[b]	0.15	< 0.001	< 0.001	0.070
Loin depth, cm.[4]	6.40[a]	6.26[ab]	6.23[ab]	6.19[b]	6.11[b]	6.24[ab]	6.13[b]	0.05	< 0.001	0.831	0.809
Back fat depth cm.[4]	1.93[ab]	2.03[a]	2.04[a]	1.86[b]	1.96[ab]	2.01[ab]	2.02[ab]	0.04	0.007	0.003	0.181
Overall[5]											
HCW, kg	97.1[a]	97.7[a]	95.8[a]	92.4[b]	96.3[a]	96.6[a]	97.6[a]	0.80	< 0.001	< 0.001	0.014
Carcass yield, %	72.3[a]	72.0[ab]	71.6[bc]	71.3[c]	72.0[ab]	71.8[abc]	71.7[abc]	0.16	< 0.001	0.192	0.012
Lean, %[4]	53.0[a]	52.5[b]	52.6[ab]	52.7[ab]	52.7[ab]	52.6[b]	52.6[b]	0.11	< 0.001	0.259	0.868
Loin depth, cm.[4]	6.21[a]	6.07[b]	6.11[ab]	6.02[b]	6.07[b]	6.11[ab]	6.06[b]	0.03	0.004	0.277	0.119
Back fat depth, cm.[4]	1.92	2.00	1.98	1.91	1.93	1.98	1.97	0.02	0.019	0.040	0.372

[1]A total of 3,055 pigs (initially 22.5 kg) were used with 30-36 pigs per pen and 13 replications per treatment to collect carcass data.

[2]Pigs were either fed diets containing 0% DDGS with 19% standardized ileal digestible (SID) Trp:Lys ratio from day 0 to 119/120, 30% DDGS from d 0 to 70 and 0% DDGS from d 70 to 119/120 with SID Trp:Lys ratios of 19% from d 0 to 119/120 or 19% from d 0 to 70 and 25% SID Trp:Lys from d 70 to 119/120, or fed 30% DDGS from d 0 to 119/120 with levels of SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[3]Linear and quadratic contrasts included treatments containing 30% DDGS and a SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[4]Adjusted using HCW as a covariate.

[5]Weighted average of carcass characteristics for the overall study.

[a,b,c] Means in the same row that do not have a common superscript differ ($P < 0.05$).

Table 2-7 Effects of Trp:Lys ratios and DDGS withdrawal strategies on carcass fat iodine value of growing finishing pigs[1]

DDGS, %[2]:	0	30-0 withdrawal		30 throughout					*P* =		
SID Trp:lys, %[2]:	19	19	19-25	16	19	22	25	SEM	Treatment	Linear[3]	Quadratic[3]
Item											
Iodine value, %											
Number of pigs	76	72	73	75	70	80	74	-	-	-	-
1st Cut	64.66[c]	72.91[b]	73.52[b]	75.37[a]	75.75[a]	75.45[a]	75.59[a]	0.47	< 0.001	0.824	0.741
Number of pigs	73	74	72	71	73	68	76	-	-	-	-
2nd Cut	64.04[c]	70.78[b]	71.40[b]	76.14[a]	75.32[a]	75.65[a]	75.20[a]	0.37	< 0.001	0.117	0.589
Number of pigs	52	48	63	58	55	51	52	-	-	-	-
3rd Cut	63.93[c]	70.31[b]	70.81[b]	76.12[a]	76.80[a]	77.33[a]	77.27[a]	0.49	< 0.001	0.057	0.422
Overall[4]	63.13[c]	71.23[b]	71.80[b]	75.97[a]	75.82[a]	75.26[a]	75.92[a]	0.25	< 0.001	0.798	0.515

[1]A total of 6,240 pigs (initially 22.5 kg) were used with 30-36 pigs per pen and 26 replications per treatment. Fat samples were collected from the dorsal loin-butt junction and were immediately frozen and later analyzed for iodine value using Near Infrared Spectroscopy (NIR).

[2]Pigs were either fed diets containing 0% DDGS with 19% standardized ileal digestible (SID) Trp:Lys ratio from day 0 to 119/120, 30% DDGS from d 0 to 70 and 0% DDGS from d 70 to 119/120 with SID Trp:Lys ratios of 19% from d 0 to 119/120 or 19% from d 0 to 70 and 25% SID Trp:Lys from d 70 to 119/120, or fed 30% DDGS from d 0 to 119/120 with levels of SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[3]Linear and quadratic contrasts included treatments containing 30% DDGS and a SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[4]Weighted average of carcass fat iodine value by pen.

[a,b,c] Means in the same row that do not have a common superscript differ ($P < 0.05$).

Table 2-8 Effects of increasing Trp:Lys ratios and DDGS withdrawal strategies on economics of growing finishing pigs[1]

DDGS, %[2]:	0	30-0 withdrawal		30 throughout					*P* =		
SID Trp:Lys, %[2]:	19	19	19-25	16	19	22	25	SEM	Treatment	Linear[3]	Quadratic[3]
Item											
Economics											
Revenue, $/pen[4]	5,235	5,183	5,117	4,999	5,149	5,103	5,044	73.9	0.074	0.724	0.071
Feed cost, $/pen	2,994[a]	2,960[ab]	2,953[ab]	2,860[b]	2,902[ab]	2,897[ab]	2,906[ab]	54.8	0.008	0.255	0.535
IOFC, $/pen[5]	2,241	2,222	2,164	2,139	2,248	2,206	2,138	95.8	0.100	0.775	0.012
Feed cost/kg gain[6]	0.795[a]	0.784[bcd]	0.792[abc]	0.786[abcd]	0.786[d]	0.782[cd]	0.792[ab]	0.01	< 0.001	0.074	0.002
Revenue, $/pig placed[7]	150.05[a]	149.55[a]	146.17[ab]	143.51[b]	148.52[ab]	146.59[ab]	148.35[ab]	2.69	0.016	0.043	0.240
Feed cost, $/pig placed[8]	85.54[a]	85.06[ab]	84.07[ab]	81.78[b]	83.33[ab]	82.93[ab]	84.91[a]	1.04	< 0.001	0.002	0.732
IOFC, $/pig placed[9]	64.52	64.50	62.10	61.73	65.19	63.66	63.43	3.13	0.057	0.368	0.040

[1]A total of 6,240 pigs (initially 22.5 kg) were used with 30-36 pigs per pen and 26 replications per treatment.

[2]Pigs were either fed diets containing 0% DDGS with 19% standardized ileal digestible (SID) Trp:Lys ratio from day 0 to 119/120, 30% DDGS from d 0 to 70 and 0% DDGS from d 70 to 119/120 with SID Trp:Lys ratios of 19% from d 0 to 119/120 or 19% from d 0 to 70 and 25% SID Trp:Lys from d 70 to 119/120, or fed 30% DDGS from d 0 to 119/120 with levels of SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[3]Linear and quadratic contrasts included treatments containing 30% DDGS and a SID Trp:Lys ratio of 16, 19, 22 and 25%, respectively.

[4]Revenue, $/pen = (HCW × $0.80 × pigs marketed/pen) + (Culls × $0.45). Hot carcass weight for group 1 was calculated by taking the final body times the carcass yield for group 2.

[5]Income over feed cost, $/pen = revenue, $/pen – feed cost, $/pen.

[6]Feed cost/lb gain = total feed cost per pig divided by total gain per pig.

[7]Revenue, $/pig placed = Revenue, $/pen divided by number of pigs placed per pen.

[8]Feed cost, $/pig placed = Feed cost, $/pen divided by number of pigs placed per pen.

[9]Income over feed cost, $/pig placed = Revenue, $/pig placed – Feed cost, $/pig placed.

[a,b,c,d] Means in the same row that do not have a common superscript differ ($P < 0.05$).