

Nutritional strategies and blood biomarker-based predictions of sow and progeny performance

by

Grady Privett

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Approved by:

Co-Major Professor
Katelyn Gaffield

Approved by:

Co-Major Professor
Joel DeRouchey

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Abstract

The three chapters of this thesis include: 1) an evaluation of a cheese co-product on sow, litter, and nursery performance fed in lactation and nursery pig diets, 2) an evaluation of sorghum inclusion in lactation diets on sow and litter performance, and 3) observed ranges of blood metabolites in sows and growing pigs. Chapter 1 consisted of 2 experiments, which used 86 sows and 395 weanling pigs, respectively, to evaluate the effect of a cheese co-product on sow, litter, and nursery pig performance. In Exp 1, the cheese co-product was added to lactation diets at 4% in replacement of soybean meal with no impact on sow or litter performance. In Exp 2, the cheese co-product was evaluated in a 2×2 factorial design with main effects of sow dietary treatment and early nursery pig diets, where it was included at 4% in partial replacement of enzyme-treated soybean meal. Both pigs weaned from sows fed the cheese co-product, and those fed diets formulated with the cheese co-product during the early nursery period had improved feed efficiency. Chapter 2 utilized 568 sows to evaluate increasing levels of sorghum compared to corn in sow lactation diets on sow and litter performance. Results in this experiment suggested that tannin-free sorghum can be used as a total replacement for corn in sow lactation diets. Chapter 3 utilized 10 sows and 141 of their progeny to evaluate the observed ranges of blood criteria over the productive lifespan of the pigs. In conclusion, these experiments provided insight into the effect of nutritional strategies in lactation on sow, litter, and progeny performance, and the blood criteria measurements over the lifespan of sows and their progeny.

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Chapter 1 - Effects of a cheese co-product fed in lactation and nursery diets on sow, litter, and subsequent nursery pig performance

Abstract

A total of 86 sows (Line 241, DNA Genetics, Columbus, NE) were used to determine the effects of a cheese co-product added to lactation diets on sow and litter performance. Sows in three separate farrowing groups (approximately 31 ± 1 sows per group) were moved into the farrowing house and blocked by parity on d 112 ± 1 of gestation. Sows then were assigned to one of two dietary treatments which consisted of a standard corn-soybean-based lactation diet (control) or the control diet with 4% cheese co-product (Pro88; Keys Manufacturing, Paris, IL, USA) added at the expense of soybean meal on a digestible Lys-basis. The addition of the cheese co-product in lactation diets did not affect sow or litter performance. Offspring from the third farrowing group (395 pigs; DNA Line 241 $\times$ 600; initially 5.8 kg) were followed into the nursery and used in a 2×2 factorial to evaluate the effects of previous sow lactation feed treatment and addition of the cheese co-product in nursery diets in a 35-d growth trial. Nursery treatments included either a control diet or the control diet with 4% added cheese co-product fed in phases 1 (d 0 to 9) and 2 (d 9 to 21) followed by a common diet fed to all pigs in phase 3 (d 21 to 35). The cheese co-product was added at the expense of enzymatically treated soybean meal in the nursery diets on a digestible Lys-basis. No sow $\times$ nursery interactions were observed. Offspring from the third group of sows fed the cheese co-product were heavier ($P < 0.001$) at weaning than those not fed cheese co-product, and this BW advantage was maintained throughout the study. There was a tendency ($P = 0.058$) for fewer pigs fed the cheese co-product in the nursery to lose body weight

from d 0 to 3 after weaning, regardless of previous sow treatment. During the nursery experimental period (d 0 to 21 post-weaning) and overall (d 0 to 35), pigs weaned from sows fed the cheese co-product tended to have increased ($P < 0.10$) gain-to-feed ratio (G:F). There were no effects on average daily gain or feed intake due to previous sow treatment. In addition, during the experimental period and overall, feeding the cheese co-product in the nursery diet increased ($P < 0.05$) G:F compared to pigs fed the control diet. In conclusion, feeding a cheese co-product either in lactation or early nursery diets at the expense of soybean meal or a specialty soy protein, respectively, increased G:F of pigs throughout the nursery period.

Key Words: cheese co-product, lactation, nursery pig, specialty protein source

Introduction

The nutrient requirements to maximize milk production during lactation frequently exceed capacity of voluntary feed intake of the sow (Noblet et al., 1990). Therefore, alternative strategies, such as the addition of specialty protein sources and feed flavors, have been investigated to meet nutrient demands, increase voluntary feed intake, and reduce body reserve mobilization (Wang et al., 2014; Kim et al., 2021; Spinler et al., 2023; Bailey et al., 2025).

Feed flavors, both savory and sweet, have been shown to increase sow feed intake during lactation (Wang et al., 2014; Silva et al., 2018; Spinler et al., 2023). These additives can increase voluntary intake by enhancing the overall palatability of a diet. Specialty protein sources, such as spray-dried animal plasma, have also been evaluated to stimulate feed intake and supply highly digestible nutrients to the sow (Kim et al., 2021; Bailey et al., 2025). However, other specialty protein sources that have naturally attractive aromas may offer a combination of these functions,

stimulating feed intake, providing highly digestible nutrients, and increasing nutrient density, which could address the sow's energy and protein needs during lactation.

In the nursery phase, the use of specialty protein sources such as spray-dried animal plasma (Bailey et al., 2025), fish meal (Jones et al., 2018), and further processed soybean meal (Stas et al., 2025) have been shown to increase growth performance. This is also due to improved diet palatability and nutrient digestibility compared to soybean meal. Interestingly, research has shown that sows fed spray-dried animal plasma during lactation had offspring with improved nursery growth performance (Kim et al., 2021). This carryover effect has implications in evaluating ingredient sources from lactation through the nursery period. Thus, feed ingredient sources that can serve both to stimulate feed intake and provide high nutrient density should be investigated to better understand potential additive and interactive effects when fed in lactation and on post-weaning performance.

Cheese manufacturing co-products, not used for human consumption, have been identified as a viable protein source for nursery pigs (Fondevila et al., 2021). The same cheese co-product evaluated in the present study has previously been shown to increase feed intake in 8 to 15 kg nursery pigs when fed up to 14% of the diet (Mallea et al., 2023). Mallea et al. (2023) also reported that cheese co-product had increased amino acid digestibility and metabolizable energy content compared to fishmeal and enzymatically treated soybean meal. Therefore, this cheese co-product may be a viable ingredient to stimulate feed intake and provide highly digestible amino acids and energy in both lactation and nursery diets.

Therefore, the first objective of this study was to determine the effect of adding a cheese co-product in sow lactation diets on sow and litter performance. The second objective was to determine the effect of the same cheese co-product on nursery performance when weaned from

sows fed with or without the same co-product. It was hypothesized that the addition of cheese co-product in lactation diet would increase sow feed intake and improve piglet performance as well as increase feed intake post-weaning.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment (IACUC #4942).

General

This study was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). Sows were housed in individual farrowing stalls measuring 1.8×2.4 m including sow and piglet area. Each stall was equipped with an automatic, dry self-feeder (Gestal Quattro Opti, Jyga Technologies, St-Lambert-de-Lauzon, Quebec, Canada) and sows and piglets had access to a cup waterer. Creep feed was not offered during lactation.

Animals and treatment structure

A total of 86 mixed parity sows (DNA 241; DNA Genetics, Columbus, NE) and litters (DNA 241 $\times$ 600) were used across three batch farrowing groups (approximately 31 ± 1 sows per farrowing group). Sows were moved into the farrowing house on d 112 ± 1 of gestation. Upon entry, sows were blocked by BW within parity and allotted to one of two dietary treatments in a randomized block design. From entry until farrowing, all sows were fed 2.7 kg/d of the control lactation diet. After farrowing and cross-fostering were complete, sows were provided ad libitum access to their treatment diet which consisted of either a standard corn-soybean meal-lactation diet (control) or the control diet with the addition of 4% cheese co-product (Pro88; Keys Manufacturing, Paris, IL; Table 1) added at the expense of soybean meal. Diets were formulated

to be balanced for standardized ileal digestible amino acids and minerals using NRC (2012) values for all ingredients except the cheese co-product, which were provided by the supplier. Diets were not balanced for energy (Table 2). There were 44 sows fed the control diet and 42 sows fed the diet containing the cheese co-product. All diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Center in Manhattan, KS.

Upon entry into the farrowing house and at weaning, sow weight, caliper score, backfat, and loin depth were measured. Caliper scores were taken at the last rib (Knauer and Baitinger, 2015). Backfat and loin depth were measured at the last rib, 10 cm from the midline on the right side of the sow (IBEX Pro ultrasound, E.I. Medical Imaging, Loveland, CO). Daily feed disappearance was recorded for each sow using the computerized feeding system. Any feed wastage taken out of the feed pan was weighed and subtracted from feed disappearance recorded for that sow. At the end of each group, all feed pans were dumped. The remaining feed was weighed and subtracted from the feed disappearance for the sow.

The number of pigs born alive, stillborn, and mummified were recorded for each sow throughout farrowing. On d 1 after farrowing, litters were processed, with litter size and individual piglet weights being collected along with the sows' post-farrowing weight. Litters of pigs were cross fostered across treatments to equalize litter size to 12 to 16 piglets per sow within 48 h of birth. Piglets were individually weighed, and litter size was recorded on d 2 after equalization, d 10 of lactation, and at weaning (d 18). After weaning, sows were moved to individual gestation stalls and checked daily for signs of estrus using once daily boar exposure. The wean-to-estrus interval (WEI) was recorded.

Pigs weaned from sows in the third farrowing group were used in the nursery portion of the study. Of the 415 pigs weaned from the third sow group, a total of 20 pigs were excluded due

to illness or lameness, including 9 pigs from sows fed the control diet and 11 pigs from sows fed the cheese co-product diet. The remaining 395 weanling pigs (initially 5.8 ± 0.02 kg) were selected to represent the population of both sow treatments in a 35-d growth trial. Pigs were weaned at approximately 18 d of age and placed into pens of 5 pigs per pen balanced for sex and sow parity. Pens were allotted within previous sow treatment to either a control diet or a diet with the addition of 4% cheese co-product. Treatment diets were fed in phases 1 (d 0 to 9) and 2 (d 9 to 21), followed by a common diet fed to all pigs in phase 3 (d 21 to 35). The phase 1 diet was pelleted, and phases 2 and 3 were fed in mash form. The cheese co-product was added at the expense of enzymatically treated soybean meal (HP 300; Hamlet Protein, Findlay, OH) and corn with feed-grade amino acids adjusted to maintain similar standardized ileal digestible (SID) amino acid (AA) concentrations as the control diets. Dietary treatments were arranged in a 2×2 factorial with main effects of previous sow treatment (control vs. cheese co-product) and nursery treatment (control vs. cheese co-product). There were 19 to 21 replications per treatment because of differences in the number of pigs weaned between the two sow treatments.

Phases 1 and 2 diets were formulated to 1.35% SID Lys, and salt was adjusted to balance the sodium and chloride levels of the diets within each phase. All other nutrients were formulated to meet or exceed the NRC (2012) requirement estimates. Nutrient loading values for the cheese co-product were provided from the supplier with the other ingredient loading values obtained from the NRC (2012). The diets were not formulated to be isocaloric (Table 3).

Pigs and feeders were weighed on d 3, 9, 17, 21, 24, 31, and 35 to determine average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F). Feeders were weighed daily from d 0 to 9 to determine daily feed intake immediately after weaning. The percentage of pigs that lost weight from d 0 (weaning) to 3 was also calculated.

Statistical analysis

Sow and litter performance data were analyzed as a generalized block design using R software, version 4. 4. 0 (R Core Team. Vienna, Austria). Sow and litter were considered the experimental unit. Treatment served as a fixed effect with a random effect of block (sow parity and group). Pre-wean mortality was analyzed using a binomial distribution. The count of litter size was analyzed using a negative binomial distribution. Two of the original 44 sows on the cheese co-product treatment were taken off test due to illness. For the nursery portion of the study, performance data were analyzed using R software (version 4.4.1, R Foundation for Statistical Computing, Vienna, Austria). Data were analyzed as a randomized block design for a two-way ANOVA using the lm function with pen considered as the experimental unit. Treatment and block served as fixed effects. Daily feed intakes from d 0 to 9 post-weaning were analyzed using the lm function in R using an unstructured covariance matrix for repeated measures, including fixed effects of sow treatment, nursery treatment, and their associated interaction. The percentage of pigs that lost weight from d 0 to 3 was analyzed using a binomial distribution. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results

Chemical analysis

Nutritional loading values for the cheese co-product were obtained from the manufacturer for formulation of the diets. A representative sample of the product was analyzed following diet manufacturing to verify manufacturer-reported specifications. The cheese co-product, as expected, contained approximately 40% CP, 18% EE, and 3.1% Lys. The analyzed mineral content of the product was similar to manufacturer specifications, with sodium content

approximately 0.64%. Additionally, the amino acid profile provided by the manufacturer was similar to that obtained from the chemical analysis.

Sow

There were no differences in sow BW, backfat, loin depth, or caliper score at entry or weaning, or in the change from entry to weaning (Table 4). No difference was observed for sow ADFI from farrowing to d 10, d 10 to weaning, or from farrowing to weaning. There were no differences observed for subsequent wean-to-estrus interval between sows fed the control diet or those fed the cheese co-product. For litter performance, there were no differences in litter size on d 2, d 10, or at weaning (Table 5). There were also no differences observed for litter weight, litter weight CV, mean piglet BW, litter ADG, piglet ADG, or preweaning mortality throughout the lactation study.

Nursery

There were no interactions between sow and nursery treatment observed throughout the study (Table 6). At weaning, offspring from sows fed the cheese co-product were heavier ($P < 0.001$; Tables 6) than pigs from sows fed the control diet. While there was no difference in weaning weight found when combining the three farrowing groups of sows used for the overall lactation study, there was a difference with this individual farrowing group.

From 0 to 3 days post-weaning, there was a tendency for a greater percentage of pigs fed the control diet to lose weight ($P = 0.058$) compared to pigs fed diets containing the cheese co-product. However, there were no differences observed in daily feed disappearance when feeders were weighed during phase 1 (d 0 to 9; Figure 1).

Neither sow nor nursery treatment influenced phase 1 (d 0 to 9) growth performance. In phase 2 (d 9 to 21), there were no differences observed for ADG; however, pigs fed the cheese

co-product in phase 2 (d 9 to 21) had increased ($P < 0.001$) G:F and a tendency for decreased ($P = 0.086$) ADFI. For the experimental period (d 0 to 21), ADG and ADFI were not affected by sow or nursery treatment, but there was a tendency for an improvement ($P = 0.088$) in G:F in offspring of sows fed the cheese co-product in lactation diets and an increase ($P = 0.007$) in G:F when the cheese coproduct was fed in nursery diets. In phase 3 (d 21 to 35), when a common diet was fed, there was a tendency ($P = 0.074$) for pigs weaned from sows fed the cheese co-product to have increased G:F. For the overall nursery period (d 0 to 35), there were no differences observed in ADG or ADFI for offspring weaned from sows fed the cheese co-product in lactation or due to feeding cheese co-product in phase 1 (d 0 to 9) and 2 (d 9 to 21) nursery diets. However, there was a tendency for an increase in G:F when pigs were weaned from sows fed the cheese co-product ($P = 0.062$) as well as an increase in G:F when the cheese co-product was fed in nursery diets ($P = 0.028$).

Discussion

Feed flavors have been shown to increase feed intake in pigs by improving palatability through taste and smell (Frederick and Van Hugten, 2006). However, results using feed flavors to increase lactation feed intake have been variable. He et al. (2017) evaluated the effect of a milk-based feed flavor on sow lactation performance. They observed an increase in feed intake during lactation when the feed flavor was added at 0.05% of the diet but not when 0.10% was added. Wang et al. (2014) observed that a fruit-milk-anise flavor increased lactation feed intake compared to a diet without the added feed flavor. Comparing baseline ADFI of control sows from Wang et al. (2014) and He et al. (2017), feed intake was almost 2 kg less than observed in the study herein. The high basal ADFI for sows in the current study could explain the lack of improvement in ADFI when the cheese co-product was added to the diet. Like results of Wang et

al. (2014) and He et al. (2017), there were no changes in sow criteria or litter performance observed in the current study.

Spinler et al. (2023) observed that sow ADFI during lactation was unaffected by feed flavor addition in a new farrowing facility during the winter season. However, during summer in an older farrowing facility, when feed intake was lower, the feed flavor increased sow ADFI compared to the control diet. Additionally, in a study conducted by Silva et al. (2018) using the same feed flavor under tropical conditions, an increase in sow ADFI was observed in diets including the feed flavor. While the study herein was conducted during the summer months (June to September), the sows were housed in an environmentally-controlled farrowing facility that supported high feed intake, which could contribute to why there was not an increase in ADFI with the added cheese co-product. Additionally, the lack of impact on sow feed intake may be reflective of the product tested in this study being a coproduct with nutritional components that are not necessarily marketed as a flavoring agent similar to some of the research referenced above.

Specialty protein sources are used in nursery diets to partially replace soybean meal and increase early nursery performance. However, specialty protein sources are not typically used in commercial production in sow lactation diets. There is limited data to support that they can improve sow and litter performance. Kim et al. (2021) and Bailey et al. (2025) observed that 1% addition of spray-dried animal plasma in sow lactation diets tended to reduce sow body weight (BW) loss. In the present study, no difference in sow BW loss was observed. Additional studies have evaluated replacement of soybean meal in lactation diets with spray-dried plasma protein (Frugé et al., 2009), spray-dried porcine plasma (Carter et al., 2018), and fish meal (Musser et al., 1996). These experiments showed variable results on sow and litter performance. The

variability observed in sow and litter performance across experiments indicates that the effects of specialty animal protein sources in sow lactation diets is not consistent.

For the nursery study, when evaluating ADFI, there were no changes during phase 1 (d 0 to 9) between treatments. However, during phase 2 (d 9 to 21), there was a tendency for reduced ADFI and increased G:F for pigs fed the cheese co-product. In agreement with our study, Sohn and Maxwell (1991) and Mallea et al. (2023) observed decreased ADFI in pigs fed cheese co-product during the phase 2 period, but they did not find increased G:F. Mallea et al. (2023) determined that the cheese co-product had greater concentrations of ME and digestible AA compared to fish meal and enzymatically treated soybean meal. For the nursery diet formulation in the present study, the cheese co-product was added in partial replacement of enzymatically treated soybean meal. The cheese co-product had an assumed ME value of 4,676 kcal/kg (Mallea et al., 2023), while the enzymatically treated soybean meal had an assumed ME value of 3,607 kcal/kg. Therefore, when using the cheese co-product as a direct replacement, the energy density of the diets increased by about 50 kcal/kg of ME, which may partially explain the increased G:F.

It was hypothesized that piglets weaned from sows previously fed a cheese co-product would transition easier post-weaning when offered nursery diets containing the same cheese co-product which would result in increased ADFI. However, there was no difference in ADFI during the first 9 d post-weaning regardless of sow or nursery dietary treatment. Even though there was no difference observed in ADFI, there was a tendency for fewer pigs fed the cheese co-product to lose weight during the first three days of the nursery period. The reason for fewer pigs to lose weight during the first three days of the nursery period again might be related to the energy density of the cheese co-product.

Exposure to a feed flavor preweaning through the sow and creep feed has shown inconsistent effects on piglet ADG and ADFI during the early postweaning period. Wang et al. (2014) observed increase in ADG and ADFI in piglets offered a creep feed containing fruit-milk-anise flavor and weaned from sows fed a diet containing the same flavor, when piglets were subsequently offered a nursery diet containing the same product. However, Spinler et al. (2023) observed no difference in pig ADFI postweaning when offered diets with or without a feed flavor when sows had been previously fed the same flavor. Bailey et al. (2025) observed no change in piglet postweaning performance when providing a spray-dried animal plasma to the sows during lactation. Similarly, in the current study, there were no sow diet effects on ADG or ADFI of offspring during the nursery period using the cheese co-product. Because there was no creep feed provided in the current experiment with the cheese co-product only the lactation diet, this could explain why there were no significant observations recorded during the nursery period. The product may need to be fed in creep feed to see an interactive effect between production phases.

Interestingly, there was a tendency for improved G:F in pigs weaned from sows fed the cheese co-product during both the experimental and overall periods. However, these pigs were also heavier at weaning compared to piglets from the control sow group and remained heavier throughout the study. It is unclear whether the improved G:F was a direct result of the cheese co-product in the sow diet or confounded by other variables.

In conclusion, there was neither a positive nor negative effect on sow and litter performance with the addition of the cheese co-product in the lactation diet. Additionally, feeding the cheese co-product to sows during lactation and subsequently to their offspring did not increase post-weaning daily feed disappearance. While no interaction between sow and

nursery treatment was observed in overall growth performance, including this cheese co-product in lactation or nursery diets improved feed efficiency of weanling pigs.

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Table 1.1. Chemical analysis of cheese co-product (as-fed basis)

Item, %	Cheese co-product ^{1,2}	
	Manufacturer reported	Analyzed
DM	90.0	92.2
CP	40.0	42.9
EE	18.0	18.9
Crude fiber	2.5	3.9
Ash	10.0	7.3
Ca	0.86	0.77
Mg	---	0.19
P	0.79	0.95
K	---	1.60
Na	0.64	0.63
S	---	0.31
Cu, mg/kg	---	9.5
Fe, mg/kg	---	53.9
Mn, mg/kg	---	21.1
Zn, mg/kg	---	57.6
Amino acids, %		
Ala	1.75	1.66
Arg	2.49	2.77
Asp	4.14	4.45
Cys	0.46	0.40
Glu	8.05	8.32
Gly	1.42	1.38
His	1.18	1.14
Ile	2.16	1.94
Lys	3.05	3.11
Met	0.81	0.73
Phe	2.25	2.08
Pro	2.96	3.05
Ser	2.02	1.83
Thr	1.67	1.28
Trp	0.59	0.53
Tyr	1.90	1.76
Val	2.45	2.35

¹A sample of the cheese co product was collected, homogenized, subsampled, and submitted to Midwest Labs (Omaha, NE) for proximate analysis and amino acid profile.

²Expected values were provided by the manufacturer and used for diet formulation; chemical analysis was conducted post diet formulation.

Table 1.2 Composition of lactation diets (as-fed basis)

Item	Control	Cheese co-product
Ingredient, %		
Corn	73.95	74.16
Soybean meal, 47.7% CP	21.95	17.74
Cheese co-product ¹	----	4.00
Calcium carbonate	1.43	1.33
Monocalcium P, 21.5% P	0.70	0.80
Salt	0.50	0.50
L-Lys-HCl	0.43	0.43
DL-Met	0.09	0.09
L-Thr	0.17	0.17
L-Trp	0.04	0.05
L-Val	0.25	0.25
Sow premix ²	0.50	0.50
Total	100.0	100.0
Standardized ileal digestible amino acids		
Lys, %	1.05	1.05
Ile:Lys	56	56
Leu:Lys	125	126
Met:Lys	31	32
Met and Cys:Lys	54	54
Thr:Lys	64	64
Trp:Lys	20	20
Val:Lys	85	85
His:Lys	38	38
Metabolizable energy (ME), kcal/kg	3,280	3,335
Net energy (NE), kcal/kg	2,469	2,533
SID Lys:NE, g/Mcal	4.25	4.15
CP, %	17.4	17.0
Ca, %	0.82	0.82
P, %	0.50	0.52
STTD P, %	0.40	0.40

¹Keys Manufacturing, Paris, IL.

²Ronozyme HiPhos (DSM Nutritional Products, Parsippany, NJ) provided 1,980 FTU/kg and an expected STTD P release of 0.14%. Provide per kg of diet: 8,265 IU vitamin A; 1,653 IU vitamin D; 66 IU vitamin E; 3.3 IU vitamin K; 0.03 mg vitamin B12; 49.6 mg niacin; 27.6 mg pantothenic acid; 8.3 mg riboflavin; 0.22 mg biotin; 2.2 mg folic acid; 2.2 mg pyridoxine; 551 mg choline; 49.6 mg carnitine; 110 mg Zn from zinc sulfate; 110 mg Fe from iron sulfate; 33.1 mg Mg from manganese oxide; 16.6 mg Cu from copper sulfate; 0.30 mg I from calcium iodate; 0.30 mg selenium from sodium selenite; 0.20 mg Cr from chromium picolinate.

Table 1.3 Composition of nursery diets (as-fed basis)

Ingredients, %	Phase 1 ¹		Phase 2		Phase 3
	Control	Cheese co-product	Control	Cheese co-product	Common
Corn	40.75	39.37	53.42	52.22	67.80
Soybean meal, 47.7% CP	19.86	19.85	27.42	27.33	28.13
Cheese co-product ²	---	4.00	---	4.00	---
Enzymatically treated SBM ³	7.50	5.00	3.75	1.25	---
Corn DDGS	5.00	5.00	---	---	---
Spray-dried whey powder	10.00	10.00	---	---	---
Whey permeate	11.25	11.25	10.00	10.00	---
Corn oil	1.50	1.50	1.00	1.00	---
Calcium carbonate	0.45	0.40	0.68	0.63	0.85
Monocalcium phosphate	1.35	1.40	1.30	1.30	0.95
Sodium chloride	0.38	0.33	0.55	0.48	0.60
L-Lys-HCl	0.50	0.46	0.51	0.47	0.55
DL-Met	0.24	0.24	0.24	0.23	0.21
L-Thr	0.23	0.23	0.25	0.24	0.24
L-Trp	0.04	0.04	0.04	0.04	0.06
L-Val	0.12	0.10	0.15	0.12	0.16
Trace mineral premix ⁴	0.15	0.15	0.15	0.15	0.15
Vitamin premix ⁵	0.25	0.25	0.25	0.25	0.25
Phytase ⁶	0.06	0.06	0.06	0.06	0.06
Zinc oxide	0.39	0.39	0.25	0.25	---
Total	100.0	100.0	100.0	100.0	100.0
Standardized ileal digestible (SID) amino acids, %					
Lys, %	1.35	1.35	1.35	1.35	1.30
Ile:Lys	57	58	55	56	53
Leu:Lys	113	115	110	112	113
Met:Lys	38	38	37	38	36
Met & Cys:Lys	58	58	58	58	57
Thr:Lys	65	65	65	65	64
Trp:Lys	20.0	20.0	20.0	20.0	20.0
Val:Lys	70	70	70	70	70
His:Lys	34	35	35	36	35
Metabolizable energy (ME), kcal/kg	3,406	3,452	3,353	3,402	3,285
Net energy (NE), kcal/kg	2,544	2,592	2,495	2,546	2,442
SID Lys:NE, g/Mcal	5.31	5.21	5.41	5.30	5.32
CP, %	20.7	20.8	20.8	20.8	20.0
Ca, %	0.69	0.70	0.71	0.71	0.68
P, %	0.73	0.75	0.68	0.68	0.58
STTD ⁷ P, %	0.63	0.63	0.56	0.55	0.46

¹Phase 1 diets were fed from d 0 to 9. Phase 2 diets were fed from d 9 to 21. Phase 3 was fed to all pigs from d 21 to d 35.

²Pro88 (Keys Manufacturing, Paris, IL).

³HP 300 (Hamlet Protein, Findlay, OH).

⁴Provided per kg of diet: 4,134 IU vitamin A; 1,653 IU vitamin D; 44.1 IU vitamin E; 3.3 mg vitamin K; 0.03 mg vitamin B12; 49.6 mg niacin; 27.6 mg pantothenic acid; 8.27 mg riboflavin.

⁵Provided per kg of diet: 110 mg Zn from Zn sulfate; 110 mg Fe from iron sulfate; 33 mg Mn from manganese oxide; 16.5 mg Cu from copper sulfate; 0.30 mg I from calcium iodate; 0.30 mg Se from sodium selenite.

⁶Ronozyme HiPhos (DSM, Parsippany, NJ) included at 1,486 FTU/kg provided an estimated release of 0.12% STTD P.

⁷STTD = Standard total tract digestible

Table 1.4 Evaluation of a cheese co-product in lactation diets on sow performance

	Control ^{1,2}	Cheese co-product	SEM	<i>P</i> =
Count, n	44	42	---	---
Parity	2.0	2.0	0.37	0.882
Lactation length, d	18.7	18.7	0.30	0.798
Sow BW, kg				
Entry	246.2	247.4	10.19	0.681
Farrow	223.5	226.6	8.59	0.351
Weaning	216.1	219.3	8.68	0.328
Change (farrow to weaning)	-7.1	-7.4	1.50	0.984
Change (entry to weaning)	-29.9	-28.0	2.94	0.455
Sow backfat, mm				
Entry	14.4	14.7	0.40	0.547
Weaning	12.5	12.8	0.40	0.604
Change (entry to weaning)	-1.9	-1.9	0.31	0.895
Sow loin depth, mm				
Entry	50.6	51.8	1.04	0.303
Weaning	46.4	47.3	0.80	0.335
Change (entry to weaning)	-4.2	-4.4	0.74	0.808
Sow caliper score, units				
Entry	15.3	15.6	0.30	0.390
Weaning	13.6	13.9	0.39	0.354
Change (entry to weaning)	-1.7	-1.6	0.25	0.890
Sow ADFI, kg				
d 2 to 10	5.4	5.3	0.24	0.545
d 10 to weaning	8.4	8.1	0.32	0.409
Farrow to weaning	6.8	6.6	0.19	0.181
Wean to estrus interval, d	5.4	5.4	0.12	0.916

¹A total of 86 mixed-parity sows (Line 241, DNA, Columbus, NE) were used.

²Sow treatment consisted of a control diet or the control diet with 4% added cheese co-product (Pro88; Keys Manufacturing, Paris, IL) fed from d 2 post-farrow until weaning.

Table 1.5 Evaluation of a cheese co-product in lactation diets on litter performance

	Control ¹	Cheese co-product	SEM	<i>P</i> =
Litter size, n				
d 2	14.5	14.4	0.59	0.906
d 10	14.1	13.8	0.57	0.704
Weaning	14.0	13.7	0.57	0.657
Litter weight, kg				
d 2	24.1	24.3	0.91	0.878
d 10	50.7	50.1	1.57	0.671
Weaning	74.6	74.0	1.84	0.735
Mean piglet BW, kg				
d 2	1.7	1.7	0.06	0.564
d 10	3.6	3.6	0.09	0.538
Weaning	5.3	5.4	0.15	0.384
Litter ADG, kg/d				
d 2 to 10	3.12	3.07	0.107	0.632
d 10 to weaning	3.36	3.34	0.127	0.866
d 2 to weaning	3.23	3.20	0.105	0.724
Piglet ADG, g/d				
d 2 to 10	222	222	7.9	0.984
d 10 to weaning	240	244	9.5	0.544
d 2 to weaning	231	233	8.1	0.676
Litter weight CV, %				
d 2	18.8	18.9	0.74	0.922
d 10	19.9	18.3	0.92	0.155
Weaning	19.8	18.2	0.86	0.129
Preweaning mortality d 2 to weaning, %	3.2	4.6	2.80	0.457

¹A total of 86 mixed-parity sows (Line 241, DNA, Columbus, NE) and litters were used from d 2 post-farrow until weaning. Litters were cross-fostered to equalize litter size up to 48-h post-farrowing.

²Sow treatment consisted of a control diet or the control diet with 4% added cheese co-product (Pro88; Keys Manufacturing, Paris, IL) fed from d 2 post-farrow until weaning.

Table 1.6 Interactive effects of sow and nursery diets supplemented with a cheese co-product on growth performance of nursery pigs

Sow treatment ^{1,2} : Nursery treatment ³ :	Control		Cheese co-product		SEM	<i>P</i> =		
	Control	Cheese co-product	Control	Cheese co-product		Sow × nursery	Sow	Nursery
Body weight, kg								
d 0	5.6	5.6	5.9	6.0	0.02	0.662	<0.001	0.050
d 3	5.8	5.8	6.0	6.2	0.06	0.129	<0.001	0.102
d 9	7.2	7.2	7.5	7.6	0.07	0.192	<0.001	0.674
d 21	12.1	12.2	12.4	12.6	0.16	0.762	0.012	0.387
d 35	20.0	20.2	20.8	20.7	0.27	0.717	0.018	0.904
d 0 to 3								
Pigs lost weight, % ⁴	37.2	33.0	54.4	33.0	6.78	0.202	0.203	0.058
Phase 1 (d 0 to 9)								
ADG, g	180	173	173	170	7.1	0.212	0.788	0.916
ADFI, g	196	184	184	185	8.3	0.348	0.571	0.632
G:F, g/kg	925	944	944	932	28.6	0.647	0.260	0.475
Phase 2 (d 9 to 21)								
ADG, g	405	417	414	414	10.5	0.745	0.994	0.394
ADFI, g	580	559	583	562	12.1	0.991	0.803	0.086
G:F, g/kg	699	747	709	737	10.9	0.345	0.999	<0.001
Experimental period (d 0 to 21)								
ADG, g	280	280	284	291	6.7	0.583	0.265	0.632
ADFI, g	353	338	349	340	8.7	0.739	0.868	0.167
G:F, g/kg	798	831	816	863	14.5	0.616	0.088	0.007
Phase 3 (d 21 to 35)								
ADG, g	565	570	593	577	13.1	0.391	0.179	0.670
ADFI, g	860	867	884	862	17.2	0.375	0.572	0.652
G:F, g/kg	656	656	671	669	7.8	0.893	0.074	0.885
Overall								
ADG, g	411	415	423	418	7.5	0.522	0.273	0.966
ADFI, g	593	586	601	584	10.7	0.641	0.762	0.283
G:F, g/kg	693	708	706	717	5.9	0.777	0.062	0.028

¹A total of 395 weaned pigs (DNA 241 × 600) weaned at approximately 18 d of age were used in a 35-d nursery trial with 19 to 21 pens per treatment and 5 pigs per pen.

²Sow treatment consisted of providing a control diet or control diet with 4% cheese co-product (Pro88; Keys Manufacturing, Paris, IL) in lactation.

³Nursery treatment consisted of providing a control diet or a diet with 4% cheese co-product (Pro88; Keys Manufacturing, Paris, IL) in phase 1 and 2 with a common diet fed in phase 3.

⁴Percentage of pigs that lost weight on d 3 after weaning compared to the weight obtained at weaning.

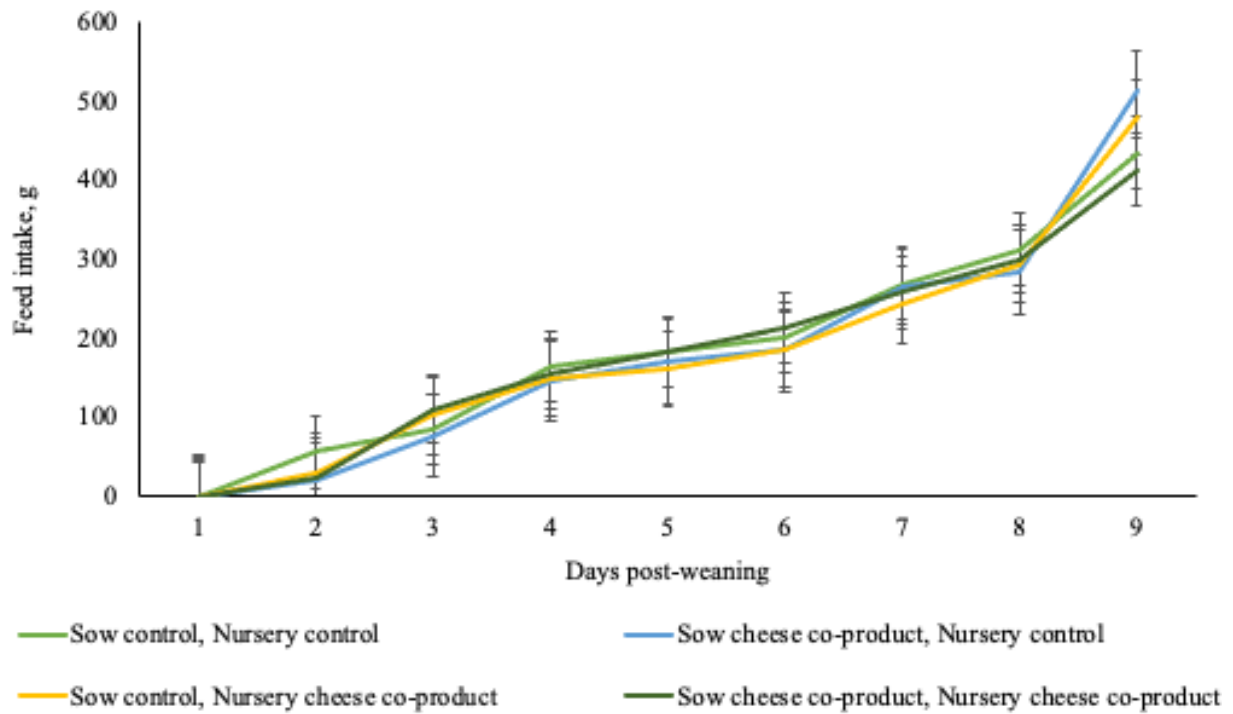


Figure 1.1 Average daily feed disappearance per pig for piglets weaned from sows fed diets with or without cheese co-product in lactation and/or nursery diets with or without cheese co-product. Feeders were weighed daily for the first 9 days post-weaning to determine daily feed disappearance in the early post-weaning phase.

Chapter 2 - Evaluation of grain sorghum in lactation diets on sow and litter performance

Abstract

A total of 568 sows (Line 1050, PIC Genetics, Hendersonville, TN) and their litters (PIC 337 × 1050) were used to evaluate the effects of grain sorghum compared to corn in lactation diets on sow and litter performance. Sows, in four separate farrowing groups (approximately 142 ± 1 sows per group), were moved into farrowing rooms and blocked by parity on d 112 ± 1 of gestation. Sows were assigned to one of three dietary treatments, consisting of diets with corn, grain sorghum or a 50:50 blend of both serving as the grain source. The grain sorghum used was a tannin-free burgundy United States grain sorghum sourced from the Texas and Oklahoma panhandles. Diets were formulated to be balanced for amino acids, minerals, and net energy. Corn and sorghum were given the same net energy value (2,672 kcal/kg). Sows were fed a wheat-based gestation diet, then hand-fed 0.90 kg of their treatment diet twice a day, starting 3 to 5 d pre-farrow, and were given ad libitum access from farrow until weaning (approximately d 19 of lactation). Particle size of grain and complete feed were analyzed. Grain sorghum was slightly finer than corn, reducing dietary particle size as sorghum inclusion increased; however, all diets remained within a 30 µm range. Replacing corn with grain sorghum in the diet did not affect sow weight, backfat, or caliper score change from entry to weaning. Feeding sows grain sorghum did not affect sow average daily feed intake, litter feed efficiency, or wean-to-estrus interval. There were no differences in total born or born alive. However, there was a decrease (quadratic, $P = 0.003$) in the percentage of stillborn pigs with increasing grain sorghum in the diet. Also, the

percentage of mummies increased and then decreased (quadratic, $P = 0.001$) as grain sorghum inclusion increased. There were no differences in litter size or litter weight after cross-fostering (d 1) or at weaning. Prewaning mortality tended to decrease then increase (quadratic, $P = 0.080$) with increasing grain sorghum in the diet. As grain sorghum increased, preweaning removals increased (linear, $P = 0.046$); however, no differences were observed in total removals and mortality. In conclusion, grain sorghum can replace corn in lactation diets with little impact on sow or litter performance.

Key Words: Grain sorghum, lactation, litter performance, sow

Introduction

Feed represents the largest component of production costs in the swine industry (Niemi et al., 2010). Corn is the most common cereal grain (energy source) used in swine diets in the United States. Therefore, identifying alternative cereal grains, when economically viable, that can partially or completely replace corn without negative effects on pig performance is important for improving efficiency in swine systems.

Grain sorghum is commonly grown across various regions of the United States due to its drought tolerance (Schober and Bean, 2008). Because of increased production in the Great Plains region, grain sorghum can have an economic advantage compared to corn in swine diets. Nutritionally, grain sorghum contains similar concentrations of energy compared with corn, making it a potential alternative cereal grain for swine diets (NRC, 2012). Historically, grain sorghum has been associated with differences in feed intake due to the tannin concentration (Cousins et al., 1981). However, 99% of the grain sorghum currently grown in the United States

is tannin-free (Palacios et al., 2021). Additionally, advancements in feed processing and the use of standardized ileal digestible amino acids in diet formulation have improved the nutritional value and overall usability of grain sorghum in swine diets. Multiple studies have evaluated grain sorghum as a replacement for corn in nursery and finisher pigs, and have shown that grain sorghum is a suitable replacement for corn and can be added with few negative effects on pig performance (Benz et al., 2011; Thomas et al., 2020)

During lactation, sows have high nutrient requirements to support milk production and maintain body condition (Tokach et al., 2019). The choice of dietary ingredients providing energy may influence sow feed intake, body weight change, and litter growth performance. Previous studies have evaluated grain sorghum in lactation diets and reported variable effects on sow feed intake, body weight change, and litter performance (Louis et al., 1991; Johnston et al., 1998; Kim et al., 2002; Sotak-Peper et al., 2015). However, these studies were conducted under small-scale university conditions with sows that had much smaller litters and lighter litter weaning weights compared with current production standards. Therefore, additional research is needed to evaluate modern tannin-free cultivars of grain sorghum as an energy source in commercial lactation diets. The objective of this study was to evaluate the effects of using grain sorghum as a partial or complete replacement of corn in lactation diets on sow and litter performance under commercial conditions.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment (IACUC #4915).

General

This study was conducted at a commercial sow farm in northwest Texas (JBS Live Pork, Dalhart, Texas). Sows were housed in individual farrowing stalls measuring 2.1×1.5 m that included a sow and piglet area in an environmentally controlled, mechanically ventilated barn. A heat lamp was included for piglet comfort. Each stall was equipped with a SowMax feed hopper (HogSlat, Newton Grove, NC). Two feeder types were used: a dry or a wet-dry feeder (HogSlat, Newton Grove, NC). All stalls were equipped with a supplementary piglet water nipple 16.5 cm from the floor. The dry feeder included a sow water nipple located 40.5 cm from the floor, whereas the wet-dry feeder included a water nipple located 30.5 cm from the floor, with an additional water source provided within the feed pan. Dietary treatments were evenly distributed across feeder configurations, and feeder configuration did not influence the response to dietary treatment.

A total of 568 sows (average parity 2.5, Line 1050, PIC, Hendersonville, TN, United States) and litters (PIC 337 $\times$ 1050) were used across four farrowing groups (approximately 142 ± 1 sows per farrowing group) from September to November 2025. During gestation, all sows were provided a common wheat-based diet. On d 112 ± 1 of gestation, sows were moved into farrowing rooms, blocked by parity, and assigned to dietary treatments, which were fed from entry into the farrowing house until weaning. Parity blocks included: first parity, parity 2 to 4, and parity 5 and greater. During each placement, first parity sows were assigned to the two middle rows of the room, while multiparous sows filled the remaining stall spaces. Dietary treatment consisted of diets with corn, grain sorghum or a 50:50 blend of both serving as the grain source. (Table 1). The grain sorghum used was a tannin-free burgundy United States grain sorghum sourced from the Texas and Oklahoma panhandles. There were 189 or 190 sows for

each dietary treatment. From entry until farrowing, sows were hand-fed 0.90 kg twice a day, after which feed was offered ad libitum. No creep feed was offered to piglets throughout lactation. Diets were fed in mash form and formulated to be balanced for amino acids, minerals, and net energy (NE) using NRC (2012) nutrient values for ingredients, except for NE of grain sorghum. Corn and grain sorghum were given the same estimated NE value in diet formulation (2,672 kcal/kg). Both grains were ground using a twin-rotor hammer mill equipped with a 12-mm screen followed by a 10-mm screen to achieve a target particle size of 500 μ m. Grain particle size was measured after each grain grinding event and all complete diets were sampled and analyzed after delivery to the farm. Particle size of grain and complete feed were analyzed with a 13-sieve system with the inclusion of a flow agent and a 15-min run time following standard sieving procedures (Table 2; Stark and Kalivoda, 2016). All diets were manufactured and particle size was analyzed at the JBS Dalhart Feed Mill (Dalhart, TX).

Upon entry into the farrowing house and at weaning, sow weight, caliper score, and backfat were measured. Caliper scores were taken at the last rib (Knauer and Baitinger, 2015). Backfat was measured at the last rib, 10 cm from the midline on the left side of the sow (Renco Lean Meter, S.E.C. Repro Inc., Golden Valley, MN). Daily feed additions were recorded for each sow using a scale cart and the LeeO system (Merck Animal Health, Madison, NJ). Each farrowing crate had an attached radio frequency identification (RFID) tag which identified its location in the LeeO system. When sows were moved into the farrowing stall, they were registered by location in the LeeO system.

Refused feed was removed from the feed pan at weaning, weighed, and subtracted from the recorded feed disappearance for each sow. The dry matter (DM) content of the recovered feed was analyzed to calculate feed removed on a DM basis, and diet DM was subsequently used

to convert feed removed to an as-fed basis for accurate adjustment. Approximately 28% of all sows had refused feed, with the percentage of sows with refused feed at weaning being similar across dietary treatment. Additionally, feeder measurements were taken at farrowing to account for feed remaining in the feeder. The feeder measurement at farrowing was added to the sow's total intake, whereas the feeder measurement at weaning was subtracted from the sow's total intake.

The number of total born, born alive, stillborn, and mummified piglets was recorded for each sow throughout farrowing. Cross-fostering occurred across dietary treatments to equalize litters within 24 h of farrowing. Piglets were weighed as a litter on d 1 post cross-fostering and the day before weaning. Litter feed efficiency was calculated by dividing the total litter weight gain by the total sow feed intake from farrow to weaning. Starting on d 3 of lactation, piglets that were gaunt were removed as a fall-behind pig. All pigs removed and mortalities were weighed and recorded. After weaning, the insemination date was recorded (CloudFarms system, BASF, Florham Park, NJ, United States) and used to calculate the wean-to-estrus (WEI) for each sow. Sows were monitored daily for signs of estrus for 30 d post-weaning. Sows that did not exhibit estrus within this timeframe were culled.

Chemical analysis

Grain and diet samples were collected. Samples of both corn and grain sorghum were collected at 3 timepoints. Diet samples were collected as feed trucks were loaded before delivery to the farm. Both grain and diet samples were stored at -20°C until they were homogenized, subsampled, and submitted for analysis. Grain and diet samples were sent for the determination of amino acids (AOAC 994.12), moisture (AOAC 930.15), crude protein (AOAC 990.03), ether

extract (AOAC 2003.05), minerals (AOAC 985.01), and ash (AOAC 942.05; Midwest Laboratories, Omaha, NE; Tables 3 and 4).

Statistical analysis

Performance data were analyzed as a generalized block design using R software, version 4.4.1 (R Core Team, Vienna, Austria). Sow was considered the experimental unit. Dietary treatment and feeder treatment served as fixed effects with random effects of block (sow parity nested within farrowing group) and farrowing group. Pre-planned linear and quadratic contrast statements were used to evaluate increasing grain sorghum as a partial or complete replacement of corn in the diet. Pre-weaning mortality was analyzed using a binomial distribution. Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results

Ingredient and diet analysis

Nutrient loading values, except for NE, for the corn and grain sorghum were based on NRC (2012). Subsequent chemical analysis of the grain sources confirmed that the analyzed values for AA, DM, crude protein, ether extract, and ash were similar to the values used in formulation (Table 3). Additionally, for the complete diets, results of chemical analysis indicated nutrient profiles were consistent with expected formulated values (Table 4). The particle size of grain sorghum was slightly finer than corn, leading to a reduction of the dietary particle size as grain sorghum increased in the diet. This is due to the smaller whole grain size of sorghum compared to corn. However, all dietary particle sizes were within a 30 μm range (Table 2).

Sow and litter performance

There were no differences in sow body weight, backfat, or caliper score at entry or weaning, or the change from entry to weaning between dietary treatments (Table 5). No

differences were observed for sow average daily feed intake (ADFI) from farrowing to weaning. Additionally, there were no differences in sow wean-to-estrus interval as grain sorghum increased.

For litter performance, there were no differences in total born or born alive (Table 6). The percentage of stillborn piglets decreased (quadratic, $P = 0.003$) with increasing grain sorghum, with a small reduction in the 50:50 blend diet and a greater reduction in the grain sorghum diet. The percentage of mummies was greater (quadratic, $P = 0.001$) in the 50:50 blend diet, with lower values in both the corn and grain sorghum diets. There were no differences in litter size on d 1 or at weaning. There were also no differences observed for litter weight, mean piglet weight, litter average daily gain (ADG), piglet ADG from d 1 to weaning, or litter feed efficiency.

There was a tendency for a decrease then increase (quadratic, $P = 0.080$) in preweaning mortality, with the lowest mortality in the 50:50 blend diet. Additionally, there was an increase (linear, $P = 0.046$) in preweaning removals as the grain sorghum increased in the diet. However, there was no difference in total preweaning removals and mortality between dietary treatments.

Discussion

Historically, the use of grain sorghum in lactation diets has had variable results on sow performance (Louis et al., 1991; Johnston et al., 1998; Kim et al., 2002; Sotak-Peper et al., 2015). Both swine and grain sorghum genetics have changed over time, and previous research was not conducted under commercial sow production conditions, highlighting the need to re-evaluate the use of modern sorghum in lactation diets. Grain sorghum varieties used in previous research ranged from bronze to red in color and were predominantly low-tannin to tannin-free (Louis et al., 1991; Sotak-Peper et al., 2015), whereas the current study used a tannin-free

burgundy sorghum variety. Although grain sorghum color has historically been associated with tannin concentration, modern sorghum varieties often have low tannin levels regardless of kernel color, reducing the reliability of color as a predictor of feeding value (Boren and Waniska, 1992). Louis et al. (1991) evaluated either a corn-soybean meal or grain sorghum-soybean meal-based diet during gestation and lactation in a 2×2 factorial arrangement. Sows fed the grain sorghum-soybean meal diet during lactation had a 10% reduction in ADFI compared to sows fed the corn-soybean meal diet. This differs from the current study, which observed no differences in ADFI during lactation, regardless of grain sorghum level in the diet. The difference in ADFI observed in the present study compared to Louis et al. (1991) may be attributed to differences in sorghum tannin content, feed processing, and diet formulation methods. In the present study, tannin-free sorghum, similar dietary particle size across treatments, and standardized ileal digestibility of amino acids were used in diet formulation, whereas Louis et al. (1991) used sorghum containing 0.08% tannins, diets with particle sizes ranging from 975-1,191 μm , and a total Lysine content of 0.75%.

Johnston et al. (1998) evaluated grain source (corn vs. grain sorghum) and conditioner procedure (mash vs. standard steam conditioner pellets vs. expanded pellets), and observed a tendency for sows fed the grain sorghum-based diet to have a greater ADFI during lactation compared to sows fed the corn-based diet regardless of conditioner practice. However, sows in their study were fed sorghum-based gestation diets, while in the current study, sows were provided a wheat-based diet during gestation. To prevent any bias towards a specific grain, sows were offered a wheat-based gestation diet to eliminate any potential concern of an interaction between gestation grain source and lactation grain source. Sotak-Peper et al. (2015) evaluated lactation diets containing either corn or grain sorghum with or without 20% grain sorghum

distillers dried grain with solubles (DDGS). There was no difference in sow ADFI during lactation regardless of grain source, independent of DDGS level. While previous studies with grain sorghum in lactation diets has had variable effects on sow ADFI, the grain sorghum variety used in the present study can be implemented without negatively affecting lactation feed intake.

Given that lactation feed intake influences the mobilization of maternal body reserves, sow bodyweight and backfat change from entry to weaning was also evaluated. No differences were observed in sow BW change from entry to weaning in the current study, which agrees with Louis et al. (1991) and Johnston et al. (1998). However, sows fed grain sorghum-based diets lost less weight during lactation compared to those fed corn-based diets (Sotak-Peper et al., 2015). Because the corn and grain sorghum in diets used in the current study were assumed to be identical and there was no change in ADFI, this likely explains the lack of differences observed in sow BW change. Additionally, there were no differences observed in backfat (BF) change, which is in agreement with both Johnston et al. (1998) and Sotak-Peper et al. (2015). Furthermore, no differences were observed in WEI, which agrees with findings of Louis et al. (1991) and Johnston et al. (1998).

For farrowing measurements, no differences were observed in total born alive, likely because treatment diets were fed for 3 to 5 d before farrowing. There was a quadratic increase, and then decrease in the percentage of mummified pigs as grain sorghum increased. This differs from the study conducted by Louis et al. (1991), which observed no differences in the number of mummies regardless of grain source. Because diets in the present study were introduced on d 112 of gestation, the difference in mummies is likely not related to dietary treatment. Additionally, there was a quadratic decrease observed in the percentage of stillborn pigs as grain sorghum increased. This is also in contrast with Louis et al. (1991) in which no differences were observed

in the number of stillborns regardless of grain source. Although the reductions in stillborns are at a magnitude of industry relevance, further research is needed to understand the components of sorghum driving this response, as well as to replicate it in other commercial settings.

The lack of difference in litter weaning weight, piglet weaning weight, and litter or piglet gain for sows fed corn- or grain sorghum-based diets is similar to results of Johnston et al. (1998) and Sotak-Peper et al. (2015). Conversely, Louis et al. (1991) observed piglets weaned from sows fed the grain sorghum-soybean meal-based diet gained less weight and were lighter at weaning. Their results may be explained by the decreased ADFI and N digestibility for sows fed grain sorghum-based diets, combined with the greater particle size of their complete diet containing grain sorghum compared to corn, which would have reduced protein and energy digestibility (Owsley et al., 1981). These differences between the corn and grain sorghum diets could help explain the variation in responses seen compared to our study where our diets had similar particle size. Corn and grain sorghum were ground to 500 μm in the current study to prevent any whole grain sorghum barriers from entering the complete feed. In addition to piglet growth, there were no differences observed in litter size at weaning or total removals and mortality, which agrees with Louis et al. (1991), Johnston et al. (1998) and Sotak-Peper et al. (2015).

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Table 2.1 Composition of lactation diets (as-fed basis)

Item	Grain source ¹		
	Corn	50:50 blend	Grain sorghum
Ingredient, %			
Sorghum	---	34.10	68.15
Corn	68.02	34.03	---
Soybean meal, 48.2 CP%	26.17	26.09	26.08
Soybean oil	1.50	1.50	1.50
Monocalcium phosphate, 21 P%	0.63	0.59	0.55
Limestone	1.80	1.82	1.83
Salt	0.60	0.60	0.60
Lysine, 62.4% ²	0.40	0.41	0.42
DL-Met	0.07	0.09	0.10
L-Thr	0.12	0.11	0.10
L-Trp	0.02	0.01	---
L-Val	0.03	0.01	---
Sow premix ³	0.25	0.25	0.25
Feed mitigant ⁴	0.27	0.27	0.27
Phytase ⁵	0.04	0.04	0.04
Choline chloride	0.11	0.11	0.11
Total	100	100	100
Calculated analysis			
SID AA, %			
Lys	1.05	1.05	1.05
Ile:Lys	62	64	67
Leu:Lys	133	140	147
Met:Lys	30	31	32
Met and Cys:Lys	54	54	54
Thr:Lys	64	64	64
Trp:Lys	20	20	20
Val:Lys	72	72	72
His:Lys	41	40	39
Net energy (NE), kcal/kg	2,496	2,498	2,498
SID Lys:NE, g/Mcal	4.21	4.20	4.20
CP ⁶ , %	17.8	18.7	19.6
Ca, %	0.87	0.87	0.87
P, %	0.48	0.48	0.48
STTD ⁷ P, %	0.38	0.38	0.38

¹Feed was manufactured by a commercial feed mill (JBS, Dalhart, TX).

²BioLys (Evonik Industries AG, Essen Germany).

³OptiPhos Plus 2500 G (Huvepharma, Peachtree City, GA) provided 1,080 FTU/kg and an expected STTD P release of 0.12%. Provide per kg of diet: 11,023 IU vitamin A; 1,500 IU vitamin D; 73.5 IU vitamin E; 3.3 mg vitamin K; 0.03 mg vitamin B12; 44.1 mg niacin; 27.6 mg pantothenic acid; 8.3 mg riboflavin; 0.22 mg biotin; 2.2 mg folic acid; 1.1 mg pyridoxine; 125 mg Zn from zinc sulfate;

110 mg Fe from iron sulfate; 50.0 mg Mg from manganese oxide; 25.0 mg Cu from copper sulfate; 0.35 mg I from calcium iodate; 0.30 mg selenium from sodium selenite; 0.20 mg Cr from chromium picolinate.

⁴Guardian liquid (Alltech Inc, Nicholasville, KY) supplied lactic acid, propionic acid, and essential oils.

⁵OptiPhos Plus 2500 G (Huvepharma, Peachtree City, GA) provided 1,000 FTU/kg of diet for an estimated release of 0.12% STTD P.

⁶CP = Crude protein

⁷STTD = Standardized total tract digestibility

Table 2.2 Average particle size of grain sources and complete diets

Item	Grain ¹		Grain source		
	Corn	Sorghum	Corn	50:50 blend	Grain sorghum
Particle size, μm^2	504 ± 15.5	442 ± 18.2	597 ± 68.5	580 ± 27.5	571 ± 15.1
Geometric standard deviation ³	3.6 ± 0.31	3.4 ± 0.33	3.1 ± 0.29	3.0 ± 0.38	2.9 ± 0.27

¹Values represent the mean of 7 samples collected throughout the study. Particle size was determined using a 13-sieve system with the inclusion of a flow agent and a 15-min run time, following standard sieving procedures (Stark and Kalivoda, 2016).

²Values reported as mean particle size (d_{gw}) $\pm$ standard deviation.

³Values reported as geometric standard deviation (S_{gw}) $\pm$ standard deviation.

Table 2.3 Chemical analysis of grains (as-fed basis)

Item	Corn ¹	Sorghum
DM ² , %	83.8	85.9
CP ³ , %	6.5	9.6
EE ⁴ , %	3.9	2.7
Ash, %	0.87	1.25
Ca, %	<0.01	0.02
Mg, %	0.09	0.14
P, %	0.25	0.27
K, %	0.25	0.36
Na, %	<0.01	<0.01
S, %	0.08	0.09
Cu, mg/kg	1.1	2.4
Fe, mg/kg	12.7	28.1
Mn, mg/kg	3.8	15.0
Zn, mg/kg	23.1	19.0
Amino acids, %		
Ala	0.39	0.72
Arg	0.28	0.32
Asp	0.38	0.54
Cys	0.12	0.16
Glu	0.97	1.82
Gly	0.22	0.27
His	0.16	0.19
Ile	0.17	0.28
Leu	0.59	1.00
Lys	0.19	0.20
Met	0.13	0.14
Phe	0.23	0.39
Pro	0.45	0.72
Ser	0.26	0.39
Thr	0.17	0.24
Trp	0.05	0.11
Tyr	0.17	0.24
Val	0.24	0.35

¹A samples of each grain source was homogenized, subsampled, and submitted for proximate analysis, mineral analysis and amino acid profile (Midwest Labs, Omaha, NE). Values represent the mean of 3 samples collected throughout the study.

²DM = dry matter.

³CP = crude protein.

⁴EE = ether extract.

Table 2.4 Chemical analysis of diets (as-fed basis)

Item, %	Grain source ¹		
	Corn	50:50 blend	Grain sorghum
DM ² , %	86.7	87.1	87.6
CP ³ , %	18.1	18.4	19.7
EE ⁴ , %	3.2	4.3	3.4
Ash, %	3.4	4.8	4.7
Ca, %	1.08	0.97	0.99
Mg, %	0.16	0.16	0.18
P, %	0.52	0.48	0.50
K, %	0.86	0.85	0.84
Na, %	0.26	0.21	0.23
S, %	0.22	0.22	0.24
Cu, mg/kg	38.6	37.7	34.4
Fe, mg/kg	154	193	224
Mn, mg/kg	85.5	88.8	87.4
Zn, mg/kg	171	137	162

¹A sample of each diet was homogenized, sub-sampled, and submitted for proximate analysis and mineral analysis (Midwest Labs, Omaha, NE). Values represent the mean of 7 samples collected throughout the study.

²DM = dry matter.

³CP = crude protein.

⁴EE = ether extract.

Table 2.5 Comparison of grain sorghum with corn in lactation diets on sow performance

Item	Grain source ¹			SEM	<i>P</i> =	
	Corn	50:50 blend	Grain Sorghum		Linear	Quadratic
Count, n	190	189	189	---	---	---
Parity	2.5	2.5	2.5	0.51	0.692	0.920
Lactation length, d	19.3	19.2	19.3	0.84	0.682	0.423
Sow BW, kg						
Entry	281.9	282.5	282.2	12.17	0.913	0.882
Weaning	243.8	246.4	245.0	12.91	0.657	0.399
Change (entry to weaning)	-38.4	-36.1	-37.3	1.53	0.494	0.201
Sow backfat, mm						
Entry	16.9	16.9	16.8	1.09	0.536	0.893
Weaning	13.6	13.9	13.6	0.64	0.948	0.306
Change (entry to weaning)	-3.4	-3.1	-3.2	0.55	0.576	0.335
Sow caliper score, units						
Entry	17.6	17.7	17.6	0.35	0.655	0.728
Weaning	16.1	16.4	16.4	0.41	0.261	0.576
Change (entry to weaning)	-1.4	-1.3	-1.3	0.17	0.316	0.722
Sow ADFI, kg						
Entry to weaning	5.4	5.4	5.4	0.25	0.830	0.957
Farrow to weaning	6.6	6.7	6.7	0.27	0.850	0.760
Wean to estrus interval, d	5.6	5.5	5.7	0.14	0.364	0.182

¹A total of 568 mixed-parity sows and litters (PIC 337 × 1050, Hendersonville, TN) were used from farrowing until weaning. Litters were cross-fostered across dietary treatment to equalize litter size up to 24-h post-farrowing.

Table 2.6 Comparison of grain sorghum with corn in lactation diets on litter performance

Item	Grain source ¹			SEM	<i>P</i> =	
	Corn	50:50 blend	Grain sorghum		Linear	Quadratic
Total born, n	17.1	16.6	16.8	0.46	0.497	0.321
Total born alive, n	15.8	15.3	15.7	0.43	0.968	0.204
Stillborn, %	5.0	4.7	3.5	2.89	<0.001	0.003
Mummy, %	2.0	2.5	2.1	1.44	0.453	0.001
Litter size, n						
d 1	14.9	14.9	14.8	0.36	0.769	0.978
Weaning	13.1	13.1	12.9	0.31	0.547	0.660
Litter weight, kg						
d 1	22.4	22.8	22.3	0.32	0.792	0.255
Weaning	71.0	70.2	68.9	3.99	0.174	0.831
Litter feed efficiency ²	0.403	0.399	0.395	0.0099	0.503	0.974
Mean piglet BW, kg						
d 1	1.51	1.54	1.51	0.045	0.903	0.223
Weaning	5.42	5.37	5.35	0.414	0.431	0.757
Litter ADG, kg						
d 1 to weaning	2.65	2.61	2.55	0.095	0.204	0.910
Piglet ADG, g						
d 1 to weaning	202	198	197	0.01	0.338	0.864
Mortality, d 1 to weaning, %	7.6	6.4	7.3	0.52	0.606	0.080
Removals, d 1 to weaning, %	4.4	5.1	5.6	0.49	0.046	0.797
Removals and mortality, d 1 to weaning, %	12.0	11.5	12.8	0.75	0.362	0.202

¹A total of 568 mixed-parity sows and litters (PIC 337 × 1050, Hendersonville, TN) were used from farrowing until weaning. Litters were cross-fostered across dietary treatment to equalize litter size up to 24-h post-farrowing.

²Litter feed efficiency = Total litter weight gain/total feed disappearance.

Chapter 3 - Longitudinal characterization of sow and growing pig blood criteria

Abstract

A total of 10 high-health sows and 141 high-health offspring (DNA 600 × 241) from the sows' first litter were used to characterize circulating blood criteria concentrations over 3 parities of the sow and in the piglets from weaning until market. Non-fasted blood samples were collected from the same sows at entry into the farrowing house, 3 d before their first farrowing cycle, and then at weaning for their first, second, and third litters. Additionally, non-fasted blood samples were collected from each pig at weaning (d 18 of life), end of the nursery period (d 70 of life), midpoint of the finisher (d 123 of life), and end of the finisher (d 161 of life). Whole blood samples were analyzed for a panel of 24 blood criteria, including proteins, vitamins, and minerals, using iCheck (BioAnalyt, Teltow, DE), iSTAT Alinity (Abbott, Park, IL), and VetScan (Zoetis, Parsippany, NJ) -based rapid analysis technologies. Sows and offspring were fed corn-soybean meal-based diets formulated to meet or exceed the nutrient requirement estimates established by NRC (2012) and diets were typical of those fed in commercial production. All pigs were healthy throughout the course of blood collection. These data provide a broad characterization of whole blood criteria concentrations for the first three parities of sows and from weaning through harvest of the offspring from the sow's first litter.

Key Words: calcium, blood parameter, hemoglobin, phosphorus, pig, sow

Introduction

Measurement of different blood criteria is often performed for a variety of diagnostic and research purposes. Some published literature describes normal ranges (sometimes called reference values); however, the origin of these measures is often not clearly described. Furthermore, many of these values are dated and may not properly reflect current genetics, feeding practices, or management strategies. There is a need to determine the concentration of different blood criteria in modern swine production of healthy animals. Therefore, the objective was to characterize circulating blood criteria over 3 parities and the first litter pigs from weaning until market.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment (IACUC #4942). This study was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS USA).

Animals and sampling

A total of 10 sows and litters (DNA 600 × 241) were used for this analysis. The same sows were sampled at entry into the farrowing house, 3 d before their first farrowing cycle, and then at weaning for their first, second, and third litters. A total of 141 piglets from the sows' first litter were sampled at weaning (d 18 ± 1), the end of the nursery phase (d 70 ± 1 of life), a mid-timepoint in the finisher (d 123 ± 1 of life), and at the end of the finishing phase (d 161 ± 1 of life). Sows and pigs were generally considered healthy, characterized as being free from infections caused by porcine enteric coronaviruses, porcine reproductive and respiratory syndrome virus, or *Mycoplasma hyopneumoniae*. Additionally, no clinical signs consistent with active infections with *Escherichia coli* or *Salmonella* were observed.

Blood was drawn (7 mL) from sows and pig from the jugular vein. A 21-gauge $\times$ 1 in needle was used for weanling pigs, and an 18-gauge $\times$ 1.5 in needle for nursery pigs, finishing pigs, and sows. The samples were kept on a turntable in a 7 mL vacutainer tube (VACUETTE Lithium Heparin, Greiner Bio-one, Kremsmünster, Austria) for no more than 15 min before analysis. Blood samples were analyzed using three different pen-side rapid analysis methods (iSTAT CHEM8+ cartridge, Zoetis, Parsippany, NJ; Comprehensive Diagnostic VetScan Rotors, Zoetis, Parsippany, NJ; iCheck Vitamin E test, BioAnalyt, Teltow, DE). Blood criteria including alanine aminotransferase, albumin, albumin to globulin ratio, alkaline phosphatase, amylase, bilirubin, blood urea nitrogen, calcium, creatinine, globulin, glucose, phosphorus, potassium, sodium, and total protein were analyzed from 0.1 mL of whole blood using comprehensive diagnostic VetScan rotors. The anion gap, bicarbonate, carbon dioxide, chloride, hematocrit, hemoglobin, ionized calcium, and pH were analyzed from 0.1 mL of whole blood using iSTAT CHEM8+ cartridges. Circulating levels of vitamin E were analyzed from 0.5 mL of whole blood using iCheck Vitamin E test.

Performance data collection

Sow lactation performance measurements were collected from parity 1 to 3 including: total born, total born alive, percent stillborn, percent mummy, piglet birth weight, total weaned, pig weaning weight, and pre-wean mortality. During gestation, sows were housed in pens containing approximately 30 sows. During lactation, sows were housed individually in an environmentally controlled and mechanically ventilated barn. Pig body weight was collected on d 18, 70, 123, and 161 of life. Carcass data were collected at harvest for all pigs. During the nursery phase, pigs were housed in a single room, an environmentally controlled and mechanically ventilated

nursery containing 86 pens. During the finishing phase, pigs were housed in a mechanically ventilated barn containing 36 pens.

Diets provided

Although dietary treatments were not utilized for this analysis, sows and pig included in the sampling participated in other concurrent experiments. Sows included in the study were randomly assigned to dietary treatments during parity 1 only. Sows were provided common corn-soybean meal gestation and lactation diets post-weaning from parity 1 until parity 3. Pigs were utilized in independent nursery and finishing feeding trials. Dietary treatments utilized in the nursery and finishing trials were corn-soybean meal-based, formulated to represent coGrowingmmercially relevant feeding programs, and to meet or exceed NRC (2012) nutrient requirement estimates. Dietary treatments were randomized to the population of animals, with approximately an even distribution of pigs sampled across each treatment. Dietary treatments had minimal effects on blood criteria.

Statistical analysis

Descriptive statistics were used to show the means and standard deviation of each blood criteria and performance measurement collected for both sows and growing pigs at each collection timepoint.

Results

Descriptive statistics for the sow and offspring illustrate that the population sampled represented performance levels similar to those observed in commercial production (Tables 1 and 2). Sow blood criteria concentrations are shown in Table 3 and offspring blood criteria concentrations are shown in Table 4. These data provide a broad characterization of whole blood

criteria concentrations for the first three parities of sows and from weaning through harvest of the offspring from the sow's first litter.

Table 3.1 Descriptive statistics of the sow population measured

Item	Parity ¹			
	1	2	3	4
Average sow weight, lb				
Entry	453.1 ± 24.4	---	---	598.8 ± 35.3
Weaning	416.8 ± 43.1	---	---	585.6 ± 47.4
Caliper, units				
Entry	14.5 ± 2.4	---	---	16.0 ± 1.3
Weaning	12.7 ± 2.2	---	---	16.1 ± 1.4
Backfat, in				
Entry	0.53 ± 0.09	---	---	0.49 ± 0.08
Weaning	0.45 ± 0.09	---	---	0.48 ± 0.09
Loin depth, in				
Entry	1.93 ± 0.19	---	---	1.89 ± 0.16
Weaning	1.80 ± 0.15	---	---	1.93 ± 0.07
Total born, n	15.0 ± 3.8	17.7 ± 2.2	17.2 ± 2.0	17.9 ± 3.7
Total born alive, n	14.1 ± 3.7	16.6 ± 1.4	15.7 ± 2.6	15.7 ± 2.5
Stillborn, %	4.1 ± 4.8	2.5 ± 7.6	8.5 ± 10.0	5.1 ± 7.0
Mummy, %	1.9 ± 4.4	2.8 ± 5.4	0.6 ± 1.9	4.1 ± 4.2
Total weaned, n	13.5 ± 1.1	15.9 ± 0.8	12.9 ± 1.7	13.7 ± 2.1
Pre-wean mortality, %	6.1 ± 8.7	3.7 ± 4.7	16.6 ± 12.1	12.3 ± 9.9
Average piglet weight, lb				
d 1	3.3 ± 0.5	3.4 ± 0.5	3.3 ± 0.4	3.1 ± 0.2
Weaning	11.8 ± 1.8	12.2 ± 1.0	13.4 ± 0.5	13.3 ± 1.1

¹Data from 10 sows (DNA Line 241; Parity 0 to 3) were used. Values reported as mean ± standard deviation.

Table 3.2 Descriptive statistics of pig population sampled

Item ¹	
Average weight, lb	
d 18	11.6 ± 2.7
d 70	71.8 ± 12.6
d 123	185.5 ± 21.6
d 161	287.3 ± 29.1
Carcass characteristics	
Hot carcass weight, lb	229.2 ± 22.0
Percent lean, %	54.2 ± 1.7
Backfat depth, in	0.66 ± 0.19
Loin depth, in	2.63 ± 0.11

¹Data from growing pigs (DNA 241 × 600; n = 141) were used.
Values reported as mean ± standard deviation.

Table 3.3 Observed blood criteria values in healthy sows

Item ²	Sampling timepoint ¹			
	Pre-farrow	Weaning		
	Parity 1	Parity 1	Parity 2	Parity 3
Alanine aminotransferase, U/L [†]	25.6 ± 3.3	26.6 ± 5.2	36.9 ± 15.8	34.0 ± 30.2
Albumin, g/dL [†]	3.86 ± 0.26	3.69 ± 0.48	3.98 ± 0.29	4.16 ± 0.36
Albumin:globulin ratio [†]	1.30 ± 0.26	1.25 ± 0.40	1.17 ± 0.26	1.28 ± 0.30
Alkaline phosphatase, U/L [†]	57.1 ± 23.4	76.7 ± 47.9	79.8 ± 48.0	50.0 ± 34.2
Amylase, U/L [†]	843 ± 239	886 ± 216	1,054 ± 223	1,003 ± 224
Anion gap, mmol/L [*]	16.4 ± 1.2	17.0 ± 1.8	15.2 ± 2.4	16.7 ± 1.9
Bicarbonate, mEq/L [*]	27.8 ± 1.8	25.5 ± 1.6	29.9 ± 2.7	27.7 ± 1.8
Bilirubin, mg/dL [†]	0.32 ± 0.06	0.28 ± 0.06	0.29 ± 0.04	0.31 ± 0.03
Blood urea nitrogen, mg/dL [†]	7.8 ± 1.6	11.4 ± 4.3	14.3 ± 3.0	13.9 ± 3.0
Calcium, mg/dL [†]	10.7 ± 0.53	10.7 ± 0.25	11.3 ± 0.48	11.3 ± 0.45
Carbon dioxide, mmol/L [*]	28.6 ± 1.6	26.8 ± 1.8	30.7 ± 2.6	28.8 ± 2.0
Chloride, mmol/L [*]	101.4 ± 2.6	100.5 ± 1.4	99.7 ± 1.6	101.1 ± 1.7
Creatinine, mg/dL [†]	2.32 ± 0.25	1.79 ± 0.23	1.74 ± 0.19	2.43 ± 0.37
Globulin, g/dL [†]	3.07 ± 0.56	3.16 ± 0.72	3.53 ± 0.61	3.37 ± 0.61
Glucose, mg/dL [†]	89.1 ± 16.5	99.3 ± 7.5	97.6 ± 9.0	89.0 ± 12.0
Hematocrit, % PCV [*]	28.7 ± 5.1	27.3 ± 3.1	32.1 ± 1.6	31.6 ± 2.7
Hemoglobin, g/dL [*]	9.8 ± 1.7	9.3 ± 1.0	10.9 ± 0.6	10.7 ± 0.9
Ionized calcium, mmol/L [*]	1.27 ± 0.05	1.27 ± 0.04	1.25 ± 0.13	1.27 ± 0.12
pH [*]	7.47 ± 0.06	7.51 ± 0.05	7.44 ± 0.02	7.44 ± 0.04
Phosphorus, mg/dL [†]	6.96 ± 0.78	6.43 ± 0.78	6.42 ± 0.84	6.74 ± 1.27
Potassium, mmol/L [†]	4.64 ± 0.46	4.86 ± 0.38	4.96 ± 0.35	5.00 ± 0.62
Sodium, mmol/L [†]	139.9 ± 2.7	137.7 ± 2.3	140.6 ± 2.1	141.3 ± 2.8
Total protein, g/dL [†]	6.91 ± 0.50	6.85 ± 0.48	7.51 ± 0.40	7.52 ± 0.40
Vitamin E, mg/L [‡]	1.41 ± 0.10	1.79 ± 0.33	2.78 ± 0.88	2.43 ± 0.27

¹Data from 10 sows (DNA Line 241; Parity 0 to 3) were used. Values reported as mean ± standard deviation.

²All blood criteria were analyzed using an *i-STAT Alinity (Abbot, Park, IL), [†]VetScan (Zoetis, Parsippany, NJ), or [‡]iCheck Vitamin E (BioAnalyt, Teltow, DE).

Table 3.4 Observed blood criteria values in healthy growing pigs

Item ²	Day of life, d ¹			
	18	70	123	161
Alanine aminotransferase, U/L [†]	40.0 ± 12.0	35.0 ± 8.5	35.2 ± 6.9	41.3 ± 7.4
Albumin, g/dL [†]	3.07 ± 0.46	3.35 ± 0.39	3.96 ± 0.34	4.24 ± 0.28
Albumin:globulin ratio [†]	1.52 ± 0.50	1.19 ± 0.29	1.52 ± 0.28	1.64 ± 0.29
Alkaline phosphatase, U/L [†]	600.0 ± 245.6	139.7 ± 37.1	122.7 ± 23.2	115.1 ± 22.6
Amylase, U/L [†]	1,129 ± 324	1,289 ± 342	1,336 ± 337	1,307 ± 351
Anion gap, mmol/L [*]	17.0 ± 1.2	17.0 ± 1.5	16.7 ± 1.1	16.1 ± 1.4
Bicarbonate, mEq/L [*]	21.1 ± 2.2	28.3 ± 2.5	30.2 ± 1.9	30.6 ± 2.0
Bilirubin, mg/dL [†]	0.53 ± 0.14	0.22 ± 0.04	0.29 ± 0.03	0.29 ± 0.02
Blood urea nitrogen, mg/dL [†]	4.57 ± 2.46	4.02 ± 1.37	8.12 ± 3.40	11.13 ± 4.24
Calcium, mg/dL [†]	11.9 ± 0.84	12.0 ± 0.56	11.5 ± 0.39	11.7 ± 0.35
Carbon dioxide, mmol/L [*]	22.1 ± 2.2	29.4 ± 2.5	31.1 ± 1.8	31.6 ± 2.0
Chloride, mmol/L [*]	101.7 ± 2.8	102.1 ± 2.2	99.7 ± 1.8	99.6 ± 1.9
Creatinine, mg/dL [†]	0.83 ± 0.18	1.06 ± 0.71	1.47 ± 0.20	1.66 ± 0.22
Globulin, g/dL [†]	2.19 ± 0.55	2.92 ± 0.45	2.65 ± 0.34	2.65 ± 0.39
Glucose, mg/dL [†]	118.7 ± 14.9	115.4 ± 9.9	98.8 ± 8.5	91.6 ± 9.3
Hematocrit, % PCV [*]	31.3 ± 2.4	31.6 ± 3.3	33.0 ± 3.6	36.7 ± 3.6
Hemoglobin, g/dL [*]	10.6 ± 0.8	10.8 ± 1.1	11.2 ± 1.2	12.5 ± 1.2
Ionized calcium, mmol/L [*]	1.42 ± 0.06	1.41 ± 0.05	1.38 ± 0.04	1.32 ± 0.05
pH [*]	7.43 ± 0.05	7.36 ± 0.07	7.40 ± 0.06	7.36 ± 0.06
Phosphorus, mg/dL [†]	8.53 ± 1.19	9.84 ± 0.87	9.23 ± 0.59	8.62 ± 0.57
Potassium, mmol/L [†]	5.28 ± 0.81	6.88 ± 0.76	5.66 ± 0.60	5.83 ± 0.66
Sodium, mmol/L [†]	138.8 ± 4.1	146.8 ± 3.5	142.6 ± 2.1	143.2 ± 2.4
Total protein, g/dL [†]	5.25 ± 0.51	6.28 ± 0.43	6.62 ± 0.34	6.89 ± 0.35
Vitamin E, mg/L [‡]	3.78 ± 1.23	1.49 ± 0.57	1.23 ± 0.46	1.79 ± 0.48

¹Data from growing pigs (DNA 241 × 600; n = 141) were used. Values reported as mean ± standard deviation.

²All blood criteria were analyzed using an *i-STAT Alinity (Abbot, Park, IL), [†]VetScan (Zoetis, Parsippany, NJ), or [‡]iCheck Vitamin E (BioAnalyt, Teltow, DE).