Effects of adding potassium bicarbonate to diets with high or low crystalline lysine to influence dietary cation-anion difference on finishing pig growth performance

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LAY SUMMARY

Potassium, fed as potassium bicarbonate ($KHCO_3$) in this study, is essential for swine and is a key component of numerous physiological processes such as the maintenance of electrolyte balance, neuromuscular function. Feeding high levels of chloride anions, via crystalline lysine (L-Lys HCl) has been shown to negatively impact intake and growth performance of pigs. Additionally, potassium and chlorine are components in calculating dietary cation-anion difference (DCAD; $Na^+ + K^+ - Cl^-$ in mEq/kg of diet), which represents the influence of monovalent ions on the acid-base status of the animal. The objective of this research was to determine the impacts of varying DCAD levels within diets on finishing pig growth performance and carcass characteristics. In this experiment, there were no interactions between $KHCO_3$ inclusion and L-Lys HCl level, nor did either ingredient affect growth performance or carcass characteristics.

TEASER TEXT

Supplementing potassium bicarbonate ($KHCO_3$) to finishing pig diets containing either low or high levels of L-Lys HCl and the corresponding changes in dietary DCAD did not impact growth performance or carcass characteristics.

ABSTRACT:

Dietary cation-anion difference (DCAD), calculated as $Na^+ + K^+ - Cl^-$ in mEq/kg of the diet, represents the influence that monovalent cations and anions from these minerals have on the acid-base status of the animal. However, the recommended range of DCAD for optimal grow-finish swine performance is variable, which may indicate an interaction between DCAD and other ingredients. The hypothesis for this study was that the addition of potassium bicarbonate ($KHCO_3$) to increase diet DCAD when high levels of L-Lys HCl (> 0.35% diet) are used may potentially improve growth performance. A total of 1,944 pigs (PIC L337 × 1050, initially 35.2 ± 0.85 kg) were used in a 120-d study. Pens of pigs were blocked by BW and randomly allotted to 1 of 4 dietary treatments in a randomized complete block design. Treatments were arranged in a 2 × 2 factorial with main effects of $KHCO_3$ (0 or 0.4%), and L-Lys HCl level (low or high). L-Lys HCl was included between 0.13 and 0.21% in low diets, and between 0.36 and 0.43% in high diets. There were 27 pigs per pen and 18 replicates per treatment. Treatment diets were corn-soybean meal-based and formulated in four dietary phases (35 to 60 kg, 60 to 85 kg, 85 to 105 kg, and 105 to 130 kg). Dietary treatments were formulated such that in each phase the diet containing a low level of L-Lys HCl without $KHCO_3$ and the diet containing a high level of L-Lys HCl with $KHCO_3$ had similar calculated DCAD values (169 to 232 mEq/kg). Additionally, the diet with a low level of L-Lys HCl with $KHCO_3$ was formulated to have the highest DCAD in each phase (220 to 281 mEq/kg), while the diet with a high level of L-Lys HCl without $KHCO_3$ was formulated to have the lowest DCAD (118 to 182 mEq/kg). Overall, there was no evidence ($P > 0.10$) for a $KHCO_3$ × L-Lys HCl interaction or main effect for final BW or any observed growth response or carcass characteristics. The results of this study suggest that supplementing $KHCO_3$ to finishing pig diets with either high or low levels of L-Lys HCl and the corresponding changes in DCAD values did not impact growth performance or carcass characteristics.

Key Words: Carcass, crystalline lysine, dietary cation-anion difference, finishing pig, growth, potassium

List of abbreviations

ADFI, average daily feed intake

ADG, average daily gain

BW, body weight

CP, crude protein

DCAD, dietary cation-anion difference

DM, dry matter

G:F, gain-to-feed

SID, standardized ileal digestibility

STTD, standard total tract digestibility

INTRODUCTION

The use of crystalline Lys (L-Lys HCl) to replace a portion of the Lys provided by soybean meal or other intact protein sources to growing-finishing pigs is common in the swine industry. Feeding high levels of dietary Cl^- (via $CaCl_2$) has been shown to greatly decrease growth performance, potentially due to reduced feed intake, of growing finishing pigs (Yen et al., 1981; Patience et al., 1987; Jones et al., 2019), while a smaller reduction in growth performance has been observed when feeding high levels of L-Lys HCl (Gomez et al., 2002; Lee et al., 2001). This reduction in performance may have been due to a reduction in the dietary cation-anion difference (DCAD, $Na^+ + K^+ - Cl^-$, mEq/kg diet). It is known that feed intake and growth performance of pigs are related to DCAD at extreme levels with the optimum level to maximize performance hypothesized to be anywhere between 75 and 500 mEq/kg of the diet (Patience et al., 1987; Haydon et al., 1990; Dersjant-Li et al., 2001; Jones et al., 2019). Additionally, the replacement of soybean meal with L-Lys HCl in a diet reduces diet DCAD, as the level of dietary K^+ is lowered because soybean meal contains nearly seven times the concentration of K^+ of that in corn (Kephart and Sherritt, 1990; NRC, 2012). This decrease in DCAD may be rectified by the addition of monovalent cations, such as Na^+ or K^+, to balance intracellular anions, thus potentially regaining lost performance.

Numerous studies have been conducted to determine the optimum DCAD level for growth performance, utilizing a variety of monovalent ion sources with varying results. The supplementation of monovalent cations (via $KHCO_3$, KCL, or $NaHCO_3$) has been shown to recover part, or all, of the lost performance resulting from increased dietary Cl^- concentration (Yen et al., 1981; Patience et al., 1987, Dersjant-Li et al., 2001). However, the DCAD level required to optimize growth performance has varied across studies, Therefore, the objective of this experiment was to evaluate the effect of balancing DCAD levels, via added $KHCO_3$, to diets containing low or high levels of L-Lys HCl on growth performance and carcass characteristics of growing-finishing pigs.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment (IACUC #4375). This study was conducted at a commercial research-finishing site in southwest Minnesota (New Horizon Farms, Pipestone, MN). The barns were naturally ventilated and double-curtain sided, with completely slatted concrete flooring over deep pits for manure storage. Each pen (3.05 × 5.49 m) was equipped with a 5-hole stainless steel dry feeder (Thorp Equipment, Inc., Thorp, WI) and 1 cup waterer for *ad libitum* access to feed and water.

A total of 1,944 pigs (PIC L337 × 1050, initially 35.2 ± 0.85, kg BW) were used in a 120-d study, split between 2 identical barns with 27 pigs per pen and 18 replicates per treatment. Pens of pigs were blocked by initial BW and randomly allotted to 1 of 4 dietary treatments in a randomized complete block design arranged in a 2 × 2 factorial. Main effects were $KHCO_3$ (0 or 0.4%), and L-Lys HCl level (low or high). Daily feed additions to each pen were accomplished using a robotic feeding system (FeedPro, Feedlogic Corp., Wilmar, MN) able to record feed amounts for individual pens. All treatment diets were manufactured at the New Horizon Farms Feed Mill in Pipestone, MN, and fed in meal form in 4 dietary phases from approximately 35 to 60 kg, 60 to 85 kg, 85 to 105 kg, and 105 to 130 kg (Table 1).

Diets were corn-soybean meal-based and formulated with either low or high levels of L-Lys HCl with the addition of other feed-grade amino acids to maintain ratios of other AAs to Lys above requirement estimates. Dietary cation-anion difference values were calculated using the following equation derived by Mongin (1981): DCAD, mEq/kg = (Na^+ × 434.98) + (K^+ × 255.74) – (Cl^- × 282.06) using NRC (2012) mineral estimates for ingredients. Dietary treatments were formulated such that in each phase the diet containing a low level of L-Lys HCl (0.14 to 0.21% depending on phase) without $KHCO_3$ had a similar calculated DCAD as the diet containing a high level of L-Lys HCl (0.36 to 0.43% depending on phase) with $KHCO_3$. The DCAD for these two treatments were approximately 230, 200, 184, and 169 mEq/kg (phase 1, 2, 3, and 4, respectively). The diets with low levels of L-Lys

HCl with $KHCO_3$ had the highest DCAD in each phase (approximately 50 mEq/kg above the low L-Lys HCl without $KHCO_3$ diet), while the diets with a high level of L-Lys HCl without $KHCO_3$ had the lowest DCAD (approximately 50 mEq/kg below the high L-Lys HCl with $KHCO_3$ diet).

Pens of pigs were weighed, and feed disappearance measured approximately every 14 d to determine ADG, ADFI, and G:F. The 3 heaviest pigs from each pen were marketed on approximately d 98 and included in the growth performance data, but not in carcass data. At the completion of the study, final pen weights were taken, individual pigs were tattooed with a pen identification number, and transported to a commercial abattoir (JBS, Worthington, MN) for processing and carcass data collection. Carcass measurements included HCW, backfat depth, loin depth, and percentage lean. Carcass yields were then calculated by the pen average HCW from the plant divided by the pen average final BW on the farm.

Chemical Analysis

Diet samples were collected from feeders from each treatment during intermediate weighing events for each dietary phase and were stored at -20°C until chemical analysis. Sub-samples of each diet for each dietary phase were ground with a food processor to create a homogeneous sample and then submitted for analysis of DM (method 935.29; AOAC Int., 2012) and CP (method 990.03; AOAC Int., 2012;Ward Laboratories, Inc. Kearney, NE), as well as Na^+ (method 990.08; AOAC Int., 2012), Cl^- (method 969.10; AOAC Int., 2012), and K^+ (method 968.08; AOAC Int., 2012) analysis (Kansas State University Research and Extension Soil Testing Laboratory, Manhattan, KS; Table 2). Analyzed mineral values were used to determine analyzed DCAD values ($Na^+ + K^+ – Cl^-$ in mEq/kg of the diet).

Statistical Analysis

Data were analyzed as a randomized complete block design for two-way ANOVA using the lmer function from the lme4 package in R (Version 3.5.2, R Core Team. Vienna, Austria), with pen considered as the experimental unit, and initial BW as a blocking factor. Response criteria were tested for the main effects and potential interactions between $KHCO_3$ and L-Lys HCl as fixed effects. Results were considered significant at $P \leq 0.05$, and a trend at $P \leq 0.10$.

RESULTS

Chemical Analysis

While analyzed mineral varied slightly from the calculated values, final DCAD values are similar to the estimated values and follow the intended trend when accounting for variation in mineral concentrations of corn and soybean meal, as well as analytical variation (Table 2).

Growth Performance

At d 58, there was marginally significant evidence ($P = 0.064$) for a main effect of $KHCO_3$ on BW, with diets containing 0.40% $KHCO_3$ having numerically greater BW (Table 3). However, during the grower period (d 0 to 58) there was no evidence ($P > 0.10$) for a $KHCO_3$ × L-Lys HCl interaction or any main effect influence on ADG, ADFI or G:F. Throughout the finishing phase (d 58 to 120) or overall (d 0 to 120), there was no evidence ($P > 0.10$) for $KHCO_3$ × L-Lys HCl interactions or main effects for ADG, ADFI or G:F. For carcass characteristics, there was no evidence ($P > 0.10$) for $KHCO_3$ × L-Lys HCl interactions or main effects for any observed response variable measured.

DISCUSSION

Dietary cation-anion difference is calculated as $Na^+ + K^+ - Cl^-$ in mEq/kg of the diet and represents the influence of monovalent cations and anions on the acid-base status of the animal. Guyton (1966) observed that the increase in blood Cl^- reduced the reabsorption of HCO_3^-, which in turn led to acidosis, potentially leading to a reduction in feed intake.

When 15 to 33 kg pigs were fed diets ranging in DCAD from -85 to 341 mEq/kg of the diet, increasing DCAD (via changes in $CaCl_2$ and $NaHCO_3$) quadratically increased ADG and ADFI

(Patience et al. 1987). A negative exponential model suggested that there was limited additional improvement to ADG or ADFI above a DCAD level of 0 to 75 mEq/kg of the diet (Patience et al. 1987). Yen et al. (1981) observed that supplementing an alkaline salt ($NaHCO_3$) to 62 to 91 kg pigs helped to partially offset the loss in appetite and performance when pigs were fed a diet that contained 4% $CaCl_2$. It is believed that this recovered performance may have been a result of increasing blood buffering capacity, as shown by increased blood HCO_3^- in pigs fed diets containing both $CaCl_2$ and $NaHCO_3$, which may explain the results found by Patience et al. (1987). Haydon et al. (1990) reported that increasing DCAD from 25 to 400 mEq/kg of diet improved ADG and ADFI of 21 to 105 kg growing-finishing pigs. Using a segmented model approach, Haydon et al. (1990) estimated that there was no further improvement in ADG or ADFI when DCAD exceeded 250 mEq/kg of diet. Similarly, Dersjant-Li et al. (2001) observed that 9 to 34 kg pigs fed diets with a DCAD of 200 or 500 mEq/kg of diet had similar ADG and ADFI, which were significantly greater when compared to pigs fed diets with a DCAD of -100 mEq/kg.

Haydon et al. (1990) suggested that high ambient temperature/heat stress may alter acid-base balance due to an increased respiration rate. This may explain why Haydon et al. (1990) observed a lower optimal DCAD when compared to the findings of Patience et al. (1987) which was conducted in an environmentally controlled facility (250 mEq/kg vs. 0-341 mEq/kg, Haydon vs. Patience). The study shown herein was conducted throughout the spring and summer (late-March to mid-August). Therefore, it is possible that a higher ambient temperature may have affected our results. Additionally, ion content within water may be a potential contributing factor. However, the well water from this experiment was not analyzed.

More recently in nursery pigs, Jones et al. (2019) supplemented increasing levels of $CaCl_2$ to reduce the DCAD level of phase 1 and 2 diets fed post-weaning. In this experiment, it was observed that increasing DCAD from 84 to 243 and 29 to 199 mEq/kg (in phase 1 and 2, respectively) improved both ADG and G:F (Jones et al., 2019). These differences in observed optimum DCAD values may be a result of the different phases of production tested in each study. The results of the current trial indicate that growing finishing pigs (35 to 130 kg) reared in a commercial environment can regulate electrolyte and acid-base balance when DCAD levels range between 100 and 289 mEq/kg of diet and have similar growth performance. These results support the findings of Patience et al. (1987) who observed little to no additional improvement in growth performance at DCAD levels above 0 to 75 mEq/kg.

Potassium is an essential dietary mineral for swine and is a key component of numerous physiological processes such as the maintenance of electrolyte balance, neuromuscular function, and serves as an intracellular monovalent cation to help balance anions as part of the Na-K pump (NRC, 2012). The dietary requirement for K^+ of 25 to 135 kg grower-finishing pigs has been estimated between 0.17 and 0.23% (NRC, 2012). While the requirement has been established, numerous studies have been conducted to analyze the effects of feeding supplemental K^+ on growth performance, digestibility, and blood criteria in pigs at various production stages, with varying results. In a study by Jesse et al. (1988), adding 0.70% potassium chloride (KCl) improved ADG in 20 to 47 kg feeder pigs but in subsequent trials, supplementing either 0.70 or 1.50% KCl did not affect ADG or feed efficiency in 19 to 50 kg pigs (Jesse et al. 1988). Similarly, Brumm and Schricker (1989) observed that supplementing 0.48, 0.96, or 1.44% KCl did not alter ADG, ADFI, or feed efficiency in 20 to 90 kg growing-finishing pigs. While there is some variability in response, collectively these results help support the finding of the current study, in which the addition of 0.40% $KHCO_3$ showed no significant impact on any observed growth response.

While the effects of supplemental K^+ and L-Lys HCl on the growth performance and carcass characteristics of swine have been extensively studied separately, there have been few studies that have analyzed these effects in tandem. The implementation of feeding high levels of L-Lys HCl to replace a large portion of the Lys provided by soybean meal to growing-finishing pigs in modern swine production has been shown to restrict growth performance of grower-finishing pigs (Lee et al., 2001; Gomez et al., 2002). These studies attempted to maintain amino acid ratios to avoid deficiencies which would result in reduced performance when replacing soybean meal with L-Lys HCl. Therefore, the reduction in growth performance may have been a result of unintentional reductions in DCAD values, as replacing soybean meal with L-Lys HCl increased the concentration of Cl^-, while reducing

K^+ in the diet (Kephart and Sherritt, 1990). Therefore, it was hypothesized that feeding supplemental K^+ may help capture this lost performance. Wahlstrom and Libal (1982) observed that supplementing 1.0% potassium acetate (CH_3CO_2K) improved ADG in diets with high L-Lys HCl (0.4%), but it had no significant effect in diets without L-Lys HCl (19 to 39 kg pigs). However, these results were contradicted by the work of Kephart and Sherritt (1990) in which they found that supplementing either 1.75% potassium glutamate or 0.95% $KHCO_3$ to diets containing 0.625% L-Lys HCl did not significantly impact ADG or feed efficiency (19 to 35 kg pigs). Similarly, Siyoto and Libal (1981) and Soto et al. (2018) found that supplementing 0.4 or 0.24% KCl, respectively, had no impact on growth responses or any observed carcass characteristics in diets containing high levels of L-Lys HCl (0.4 or 0.33% for 17 to 43 kg pigs or 111 to 134 kg pigs, respectively).

In summary, the results of the current research suggest that supplementing $KHCO_3$ to finishing pig diets with either high or low levels of L-Lys HCl and the corresponding changes in dietary DCAD did not impact growth performance or carcass characteristics.

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Table 1. Diet composition by phase (as-fed basis)[1]

Item	Phase 1		Phase 2		Phase 3		Phase 4	
L-Lys HCl:	Low	High	Low	High	Low	High	Low	High
Ingredients, %								
Corn	64.64	71.09	71.33	77.60	74.76	81.47	78.08	84.86
Soybean meal, 46.5% CP	31.67	24.57	25.35	18.42	22.14	14.72	19.08	11.67
Choice white grease	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calcium carbonate	1.00	0.98	0.90	0.90	0.85	0.85	0.80	0.80
Monocalcium P, 21% P	0.70	0.80	0.50	0.60	0.40	0.50	0.20	0.25
Sodium chloride	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys HCl	0.21	0.43	0.19	0.41	0.15	0.38	0.13	0.36
DL-Met	0.06	0.12	0.02	0.09	0.01	0.08	---	0.07
L-Trp	---	0.04	---	0.04	---	0.04	---	0.04
L-Val	---	0.12	---	0.12	---	0.13	---	0.12
Thr biomas[2]	0.06	0.18	0.03	0.16	0.02	0.16	0.04	0.16
Vitamin trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Potassium bicarbonate[5]	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-
Total	100	100	100	100	100	100	100	100
Calculated analysis								
SID AA, %								
Lys	1.12	1.12	0.95	0.95	0.84	0.84	0.75	0.75
Ile:Lys	67	56	68	56	71	56	72	56
Leu:Lys	138	123	148	130	158	137	168	144
Met:Lys	30	33	29	33	30	34	31	35
Met and Cys:Lys	56	56	56	56	59	59	61	61
Thr:Lys	61	61	61	61	63	63	66	66
Trp:Lys	19.8	19.7	19.6	19.7	20.1	20.1	20.3	20.0
Val:Lys	73	73	75	75	79	79	82	81
NE, kcal/kg	2,652	2,654	2,659	2,661	2,661	2,665	2,668	2,700
SID Lys:NE, g/Mcal	4.22	4.22	3.57	3.57	3.15	3.15	2.80	2.80
CP, %	20.7	18.3	18.2	15.8	16.9	14.4	15.7	13.2
Ca, %	0.66	0.64	0.56	0.56	0.52	0.51	0.45	0.44
STTD P, %	0.41	0.41	0.36	0.36	0.33	0.33	0.28	0.28

[1]Phase 1 was fed from approximately 35 to 59 kg, phase 2 was fed from approximately 59 to 84 kg, phase 3 was fed from approximately 84 to 104 kg, and phase 4 was fed from approximately 104 to 130 kg.

[2] THR Pro, CJ America-Bio, Downers Grove, IL.

[3] The vitamin and trace mineral premix provided per kg of premix: 36.4 g Cu, 661 mg I, 242.5 g Fe, 73 g Mn, 661 mg Se, 242.5 g Zn, 5,291,088 IU vitamin A, 1,322,772 IU vitamin D,

26,455 IU vitamin E, 2,645 mg vitamin K, 24.3 mg vitamin B_{12}, 49,604 mg niacin, 16,534 mg pantothenic acid, and 4,960 mg riboflavin.

[4] Optiphos Plus (Huvepharma, Peachtree City, GA) provided 1,742 FTU/kg of diet for an estimated release of 0.11% STTD P.

[5] Potassium bicarbonate was included at 0 or 0.40% of the diet in all phases at the expense of corn.

Table 2. Chemical analysis of diets (as-fed basis)

	Phase 1				Phase 2				Phase 3				Phase 4			
L-Lys HCl:	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High	Low	Low	High	High
Item KHCO$_3$:	-[2]	+[2]	-	+	-	+	-	+	-	+	-	+	-	+	-	+
Calculated analysis																
Na^+, %	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Cl^-, %	0.38	0.38	0.42	0.42	0.38	0.38	0.42	0.42	0.37	0.37	0.42	0.42	0.37	0.37	0.41	0.41
K^+, %	0.92	1.11	0.78	0.98	0.80	0.99	0.66	0.86	0.74	0.93	0.59	0.79	0.68	0.87	0.53	0.73
DCAD[1]	230	281	182	232	199	249	151	201	184	234	133	183	169	220	118	169
Chemical analysis[3]																
DM, %	87.9	88.3	87.8	88.2	88.1	88.0	87.6	88.0	87.1	88.1	87.3	87.5	87.1	87.6	87.5	88.0
CP, %	19.7	19.4	16.7	16.6	18.4	18.2	16.3	15.9	16.1	15.7	13.1	13.4	14.0	14.8	11.5	12.2
Na^+, %	0.30	0.29	0.38	0.24	0.39	0.30	0.34	0.33	0.26	0.17	0.23	0.23	0.27	0.21	0.29	0.20
Cl^-, %	0.47	0.45	0.58	0.37	0.60	0.47	0.52	0.51	0.40	0.26	0.35	0.36	0.41	0.33	0.45	0.31
K^+, %	0.82	1.13	0.76	0.92	0.90	0.94	0.67	0.94	0.67	0.81	0.52	0.67	0.51	0.59	0.39	0.54
DCAD	210	289	194	235	231	240	171	240	171	207	133	171	130	151	100	138

[1] Dietary cation anion difference; calculated as $Na^+ + K^+ – Cl^-$, in mEq/kg diet.

[2] Potassium bicarbonate was included at 0.40% in diets with (+) KHCO$_3$ in all phases.

[3] Composite samples were submitted to Ward Laboratories, Inc. (Kearney, NE) for DM and CP analysis, as well as Kansas State University, Research and Extension Soil Testing Laboratory (Manhattan, KS) for mineral analysis.

Table 3. Effects of potassium bicarbonate with high and low crystalline lysine levels on growing-finishing pig performance[1]

L-Lys HCl:	Low		High			*P* =		
Item KHCO3:	-[2]	+[2]	-	+	SEM	$KHCO_3$ × L-Lys HCl	L-Lys HCl	$KHCO_3$
BW, kg								
d 0	35.2	35.3	35.2	35.2	0.85	0.992	0.831	0.831
d 58	84.1	84.8	84.1	84.7	1.27	0.318	0.898	0.064
d 120	129.6	129.2	128.9	130.0	1.07	0.701	0.952	0.656
d 0 to 58								
ADG, kg	0.827	0.840	0.830	0.830	0.0074	0.184	0.433	0.126
ADFI, kg	1.703	1.717	1.717	1.707	0.0521	0.803	0.858	0.858
G:F	0.492	0.495	0.490	0.493	0.0134	0.718	0.623	0.298
d 58 to 120								
ADG, kg	0.739	0.724	0.734	0.739	0.0098	0.506	0.532	0.533
ADFI, kg	2.386	2.341	2.353	2.403	0.0276	0.218	0.544	0.917
G:F	0.310	0.310	0.312	0.308	0.0049	0.786	0.956	0.482
Overall (d 0 to 120)								
ADG, kg	0.783	0.782	0.782	0.785	0.0050	0.978	0.902	0.844
ADFI, kg	2.037	2.023	2.030	2.046	0.0260	0.705	0.574	0.947
G:F	0.385	0.387	0.386	0.384	0.0045	0.850	0.676	0.916
Carcass characteristics								
HCW, kg	96.8	96.7	96.5	96.6	0.769	0.988	0.767	0.959
Carcass yield, %	74.69	74.84	74.91	74.35	0.279	0.488	0.636	0.462
Backfat depth, cm[3]	1.64	1.62	1.65	1.67	0.029	0.392	0.154	0.872
Loin depth, cm	6.89	6.90	6.92	6.93	0.050	0.865	0.426	0.769
Lean, %	57.19	57.28	57.12	56.99	0.201	0.442	0.204	0.878

[1] A total of 1,944 pigs (PIC L337 × 1050, initially 35.2 ± 0.85, kg) were used in a 120-d study, split between 2 barns located at New Horizon Farms, Pipestone, MN, with 27 pigs per pen and 18 replicates per treatment.

[2] Potassium bicarbonate was included at 0.40% in diets with (+) $KHCO_3$ in all phases.

[3] Hot carcass weight served as a covariate for the analysis of backfat depth, loin depth, and lean, %.