Evaluation of dietary electrolyte balance on nursery pig performance[1]

Aaron M. Jones,* Fangzhou Wu,* Jason C. Woodworth,*
Steve S. Dritz†,2, Mike D. Tokach,* Joel M. DeRouchey,* and Robert D. Goodband*

*Department of Animal Sciences and Industry, College of Agriculture, Kansas State University, Manhattan, KS 66506; and †Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan, KS 66506

ABSTRACT: Increasing dietary electrolyte balance (**dEB**) has been reported to linearly improve pig growth performance up to approximately 200 to 250 mEq/kg. However, recent data indicate that increasing dietary dEB reduced growth performance of nursery pigs. To attempt to solve this discrepancy, a total of 2,880 weanling pigs (327 × 1,050; PIC, Hendersonville, TN; 5.2 kg initial BW) were used to determine the effects of increasing dEB on nursery pig performance. Pens of pigs were blocked by BW and gender on arrival. Within block, pens were randomly assigned to one of four dietary treatments. There were 30 pigs per pen (60 pigs per double-sided feeder) and 12 replications (feeder) per treatment. Dietary treatments were fed in two phases. The phase 1 diet was based on corn–soybean meal, contained dried distillers grains with soblubles (**DDGS**), spray-dried whey, and specialty protein sources, and was fed from days 0 to 8. The phase 2 (days 8 to 21) diets contained corn, soybean meal, and DDGS with reduced amounts of specialty protein sources. Dietary electrolyte balance was determined using the following equation: dEB = [(Na × 434.98) + (K × 255.74) − (Cl × 282.06)] mEq/kg. The dEB of the four phase 1 diets were 84, 137, 190, and 243 mEq/kg, and dEB of the four phase 2 diets were 29, 86, 143, and 199 mEq/kg. After feeding experimental diets for 21 day, a common, commercial corn–soybean meal diet was fed to all pigs from days 21 to 35 and contained a dEB of 257 mEq/kg. During days 0 to 8, increasing dEB increased (quadratic, $P < 0.05$) ADG, ADFI, and G:F. From days 8 to 21, increasing dEB improved ADG (quadratic, $P = 0.022$) and ADFI (linear, $P = 0.001$), resulting in an improvement (quadratic, $P = 0.001$) in G:F. Overall (days 0 to 21), increasing dEB increased (linear, $P < 0.05$) ADG, ADFI, and improved (quadratic, $P < 0.001$) G:F. When a common diet was fed to all pigs from days 21 to 35, there was a linear reduction in ADG and G:F with increasing dietary dEB, but no effect of ADFI. For the overall nursery period (days 0 to 35), increasing dEB from days 0 to 21 increased (linear, $P < 0.001$) ADG and final BW, which was the result of increased (quadratic, $P < 0.05$) G:F and marginally greater (linear, $P = 0.077$) ADFI. In conclusion, increasing dietary dEB up to 243 and 199 mEq/kg (in phases 1 and 2, respectively) in nursery diets improved growth performance of weanling pigs.

Key words: chloride, dietary electrolyte balance, growth performance, nursery pig

Transl. Anim. Sci. 2019.3:377–383
doi: 10.1093/tas/txy090

[1]Contribution number 18-389-J from the Kansas Agric. Exp. Stn., Manhattan, KS. Appreciation is expressed to Jason Tebay and Dr. Matt Allerson, Holden Farms, for their technical support and expertise in conducting the experiment.

[2]Corresponding author: dritz@ksu.edu
Received June 3, 2018.
Accepted July 11, 2018.

INTRODUCTION

Electrolytes are key minerals that can be defined as chemical substances that separate when dissolved in fluids to form positive (cation) and negative (anion) ions. Previous research has indicated that cations and anions are closely linked to the alkalinity and acidity of body fluids (Mushtaq and Pasha, 2013). In particular, the monovalent minerals Na, K, and Cl are considered strong ions because of their ability to exert significant shifts in acid–base homeostasis (Mongin, 1981). Therefore, maintaining an appropriate dietary electrolyte balance (**dEB**) is critical for pigs to achieve optimal growth performance.

Typically, ingredients such as calcium carbonate, calcium phosphate, and sodium chloride are used in swine diets to meet mineral requirements, but they also contribute to the dEB, thus potentially altering acid–base homeostasis and growth performance of pigs (Patience et al., 1987; Haydon et al., 1990; DeRouchey et al., 2003). Traditionally, the optimal dEB for pigs is reported to be approximately 250 mEq/kg (NRC, 2012), but limited research exists in this area. Recently, Guzmán-Pino et al. (2015) used $CaCl_2$ to reduce dEB and reported that nursery pigs had reduced ADG and G:F when dEB exceeded 150 mEq/kg; in addition, ADG was improved by 48.7% by decreasing dEB from 269 to 16 mEq/kg. Because many common U.S. nursery diet formulations exceed 150 mEq/kg, these results are important. However, the results from Guzman-Pino et al. (2015) contradict those who reported improved growth performance with increasing dietary dEB (Patience et al., 1987; Dersjant-Li et al., 2001; DeRouchey et al., 2003). To solve the discrepancies among literatures, this study aimed to evaluate the impact of dEB on growth performance of nursery pigs in a commercial scale research facility.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The experiment was conducted at a commercial nursery in southeast MN. Pigs were housed in pens (1.82 × 3.35 m) that were equipped with a double-sided, five-hole stainless steel dry feeder and one cup waterer for ad libitum access to feed and water. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions of experimental diets as specified. Diets were manufactured at commercial feed mills for pelleted diets (Hubbard Feeds, Mankato, MN) and mash diets (Bixby Feed Mill, Blooming Prairie, MN).

Experimental Design

A total of 2,880 weanling pigs (327 × 1,050; PIC, Hendersonville, TN; initially 5.2 kg BW) were used in a 35-d growth trial with 12 replications (feeder) per treatment. Each fence line feeder provided feed to one pen of barrows and one pen of gilts and each pen initially contained 30 pigs. On arrival, pens of pigs were blocked by average individual pig BW and gender. Within blocks, feeders (combination of two pens) were randomly assigned to one of four dietary treatments. Dietary treatments were fed in two phases. The phase 1 diet was based on corn-soybean meal and contained dried distillers grains with solubles (**DDGS**; >6 and <9% oil, NRC, 2012), spray-dried whey, and specialty protein sources and was fed from days 0 to 8 (Table 1). The phase 2 diets contained corn-soybean meal–DDGS with reduced amounts of specialty protein sources and were fed from days 8 to 21 (Table 2). Diets 1 to 4 were formulated to contain increasing dEB ranging from 84 to 243 mEq/kg during days 0 to 8 and 29 to 199 mEq/kg from days 8 to 21 after weaning. The lowest dEB diets were achieved by adding 1.17% and 1.25% $CaCl_2$ from days 0 to 8 and from days 8 to 21, respectively. Dietary Ca concentrations were maintained in the three highest dEB diets, but increased in the low dEB diet because of the increasing level of $CaCl_2$. The following equation derived by Mongin (1981): dEB, mEq/kg = (Na × 434.98) + (K × 255.74) − (Cl × 282.06) was used to determine dEB. After feeding experimental diets for 21 d, a common diet was fed from days 21 to 35 (Table 3) to all pigs and was a typical nursery diet fed in commercial production with a dEB of 257 mEq/kg. Nutrient loading values of the ingredients were adopted from NRC (2012), and diets were formulated to contain similar metabolizable energy with the exception of available P which were based on NRC (1998). Days 0 to 8 diets were prepared in pellet, whereas days 8 to 35 diets were provided in meal form. The ingredient mineral, electrolyte concentrations, energy, AA, and standardized ileal digestible AA coefficients for ingredients reported by the NRC (2012) were used in formulating diets. Pigs and feeders were weighed on days 0, 8, 15, 21, and 35 of the trial to determine ADG, ADFI, and G:F.

Table 1. Diet composition, days 0 to 8 after weaning (as-fed basis)[1]

	Dietary electrolyte balance (mEq/kg)[2]			
	84	137	190	243
Ingredient, %				
Corn	38.58	39.00	39.14	39.24
Soybean meal, 46.5% CP	17.71	17.68	17.67	17.66
Corn DDGS[3]	5.00	5.00	5.00	5.00
Fish meal[4]	4.50	4.50	4.50	4.50
HP 300[5]	2.50	2.50	2.50	2.50
Spray-dried whey	25.00	25.00	25.00	25.00
Choice white grease	3.00	3.00	3.00	3.00
Moncalcium P, 21% P	0.40	0.40	0.40	0.40
Limestone	—	—	0.26	0.55
Calcium chloride	1.17	0.78	0.39	—
Sodium chloride	0.30	0.30	0.30	0.30
L-Lys HCl	0.48	0.48	0.48	0.48
MHA[6]	0.29	0.29	0.29	0.29
L-Thr	0.20	0.20	0.20	0.20
L-Trp	0.05	0.05	0.05	0.05
L-Val	0.10	0.10	0.10	0.10
Choline chloride, 60%	0.04	0.04	0.04	0.04
Phytase[7]	0.04	0.04	0.04	0.04
Zinc oxide	0.39	0.39	0.39	0.39
Selenium premix, 0.06%	0.05	0.05	0.05	0.05
Vitamin and mineral premix[8]	0.28	0.28	0.28	0.28
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible AA, %				
Lys	1.40	1.40	1.40	1.40
Ile:Lys	55	55	55	55
Leu:Lys	111	111	111	111
Met:Lys	40	40	40	40
Met and Cys:Lys	59	59	59	59
Thr:Lys	64	64	64	64
Trp:Lys	19	19	19	19
Val:Lys	67	67	67	67
ME, kcal/kg	3,461	3,474	3,479	3,483
CP, %	21.0	21.0	21.0	21.0
Na, %	0.39	0.39	0.39	0.39
Cl, %	1.34	1.16	0.97	0.78
K, %	1.14	1.14	1.14	1.14
Ca, %	0.84	0.73	0.73	0.73
P, %	0.67	0.67	0.67	0.67
Available P, %	0.59	0.59	0.59	0.59

[1]From d 0 to 8, diets were fed from approximately 5.2 kg to approximately 5.7 kg BW.

[2]Dietary electrolyte balance was calculated using the following equation: [(Na × 434.98) + (K × 255.74) − (Cl × 282.06)].

[3]Dried distillers grains with solubles, 6 to 9% oil, (NRC 2012).

[4]Omega Special Select Menhaden Fish meal (Omega Protein, Houston, TX).

[5]Hamlet Protein (Findlay, OH).

[6]Novus International (Saint Charles, MO).

[7]Quantum Blue 5G (AB Vista Americas, Plantation, FL) provided 2,000 phytase units (FTU/kg) of diet with a release of 0.14% available P.

[8]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; 198 mg Se from sodium selenite; 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

Table 2. Diet composition days 8 to 21 after weaning (as-fed basis)[1]

	Dietary electrolyte balance (mEq/kg)[2]			
	29	86	142	199
Ingredient, %				
Corn	46.92	47.16	47.28	47.41
Soybean meal, 46.5% CP	24.70	24.68	24.67	24.66
Corn DDGS[3]	15.00	15.00	15.00	15.00
Lactose	5.00	5.00	5.00	5.00
Fish meal[4]	3.75	3.75	3.75	3.75
Choice white grease	1.00	1.00	1.00	1.00
Dicalcium P, 18.5% P	0.63	0.63	0.63	0.63
Limestone	—	0.20	0.50	0.80
Calcium chloride	1.25	0.83	0.42	—
Sodium chloride	0.35	0.35	0.35	0.35
L-Lys HCl	0.40	0.40	0.40	0.40
L-Thr	0.13	0.13	0.13	0.13
L-Trp	0.03	0.03	0.03	0.03
Zinc oxide	0.25	0.25	0.25	0.25
Iron oxide	0.10	0.10	0.10	0.10
Antibiotic[5]	0.20	0.20	0.20	0.20
Vitamin and mineral premix[6]	0.30	0.30	0.30	0.30
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible AA, %				
Lys	1.35	1.35	1.35	1.35
Ile:Lys	61	61	61	61
Leu:Lys	129	129	129	129
Met:Lys	31	31	31	31
Met and Cys:Lys	57	57	57	57
Thr:Lys	63	63	63	63
Trp:Lys	19	19	19	19
Val:Lys	69	69	69	69
ME, kcal/kg	3,131	3,139	3,142	3,146
CP, %	23.5	23.5	23.6	23.6
Na, %	0.22	0.22	0.22	0.22
Cl, %	0.99	0.79	0.59	0.39
K, %	0.84	0.84	0.84	0.84
Ca, %	0.83	0.79	0.79	0.79
P, %	0.65	0.65	0.65	0.65
Available P, %	0.36	0.36	0.36	0.36

[1]During days 8 to 21, diets were fed from approximately 5.7 kg to approximately 7.6 kg BW.

[2]Dietary electrolyte balance was calculated using the following equation: [(Na × 434.98) + (K × 255.74) − (Cl × 282.06)].

[3]Dried distillers grains with solubles, 6 to 9% oil, NRC (2012).

[4]Omega Special Select Menhaden Fish meal (Omega Protein, Houston, TX).

[5]Chlortetracycline (Aureomycin, Zoetis Animal Health, Florham Park, NJ).

[6]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; 198 mg Se from sodium selenite; 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

Table 3. Diet composition days 21 to 35 after weaning (as-fed basis)[1]

	Common diet
Ingredient, %	
Corn	38.33
Soybean meal, 46.5% CP	31.99
DDGS[2]	25.00
Choice white grease	1.00
Limestone	1.25
Dicalcium P, 18.5% P	1.03
Salt	0.50
L-Lys HCl	0.40
DL-Met	0.11
L-Thr	0.10
Vitamin and mineral premix[3]	0.30
Total	100
Calculated analysis	
Standardized ileal digestible AA, %	
Lys	1.35
Met:Lys	35
Met and Cys:Lys	59
Thr:Lys	64
Trp:Lys	18
Val:Lys	74
ME, kcal/kg	3,278
CP, %	25.39
Na, %	0.29
Cl, %	0.47
K, %	1.03
Ca, %	0.83
P, %	0.66
Available P, %	0.37
dEB,[4] mEq/kg	257
Analyzed composition, %	
DM	88.37
CP	22.48
Crude fat	5.90
Ca	0.82
P	0.64

[1]Phase 3 diets were fed from approximately 7.6 kg to approximately 15.8 kg BW.

[2]Dried distillers grain with solubles.

[3]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulfate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; 198 mg Se from sodium selenite; 3,527,360 IU vitamin A; 881,840 IU vitamin D3; 17,637 IU vitamin E; 3,307 mg riboflavin; 1,764 mg menadione; 11,023 mg pantothenic acid; 33,069 mg niacin; and 15.4 mg vitamin B12.

[4]Dietary electrolyte balance was determined by analyzing complete diets for Na, K, and Cl. Analyzed values were then used in the following equation to calculate dEB: $[(Na \times 434.98) + (K \times 255.74) - (Cl \times 282.06)]$.

Diet Sampling and Analysis

Complete diet samples in phases 1 and 2 were obtained from a minimum of six individual feeders per treatment, blended, and frozen at −20 °C for subsequent analysis. Composite samples of diets were split using a riffle splitter (Humboldt Mfg. Co., Norridge, IL) and processed through a 1-mm screen in a Willey mill (Thomas Scientific, Swedesboro, NJ) prior to analysis. All diet samples were submitted for analysis of DM (method 935.29; AOAC International, 2012), CP (method 990.03; AOAC International, 2012), and ether extract (method 920.39; AOAC International, 2012) for preparation and analyzed using an ANKOM XT20 Fat Analyzer (Ankom Technology, Fairport, NY); Ca, P, and K (method 968.08; AOAC International, 2012) for preparation using ICAP 6500 (ThermoElectron Corp., Waltham, MA); Na (method 990.08; AOAC International, 2012); and Cl (method 969.10; AOAC International, 2012; Ward Laboratories Inc., Kearney, NE).

Statistical Analysis

Feeder (one pen of barrows and one pen of gilts) served as the experimental unit. Data were analyzed as a randomized complete block design with dietary treatment as a fixed effect and block serving as the random effect in the model. Preplanned linear and quadratic polynomial contrasts were used to determine the effects of increasing dEB. The coefficients for the unequally spaced linear and quadratic contrasts were derived using PROC IML in SAS. Results were considered significant at $P \le 0.05$ and marginal effects between $P > 0.05$ and $P \le 0.10$. The PROC GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC) was used for statistical analysis.

RESULTS

Analysis of experimental diets indicated that most nutrients were similar to formulated values for phase 1 diets (Table 4). Analyzed values for Na, Ca, K, and Cl were greater across dietary treatments in phase 2 (Table 5) than formulated values; however, the treatment pattern of dEB targeted was ultimately maintained across dietary treatments fed from days 0 to 8 and from days 8 to 21.

From days 0 to 8, increasing dEB increased (quadratic, $P < 0.05$; Table 6) ADG, ADFI, G:F, and day 8 BW. From days 8 to 21, increasing dEB increased ADG (quadratic, $P = 0.022$) and ADFI (linear, $P = 0.001$) as dEB increased, resulting in an improvement in G:F (quadratic, $P = 0.001$). For the overall experimental period (days 0 to 21), increasing dEB increased (linear, $P < 0.05$) ADG, ADFI, and day 21 BW, and improved G:F (quadratic, $P < 0.001$). During days 21 to 35 (common

Table 4. Chemical analysis of phase 1 diets (as-fed basis)[1]

	Dietary electrolyte balance (dEB, mEq/kg)			
Item	84	137	190	243
DM, %	90.54	90.73	91.22	90.81
CP, %	20.95	20.85	21.10	20.95
Ether extract, %	4.60	4.80	4.70	4.70
Na, %	0.36	0.43	0.45	0.39
K, %	1.26	1.26	1.28	1.25
Cl, %	1.36	1.21	0.99	0.80
Ca, %	1.02	0.98	0.95	0.90
P, %	0.75	0.67	0.72	0.72
dEB,[2] mEq/kg	95	168	244	264

[1]Chemical analysis for complete diets was analyzed by Ward Laboratories, Inc. (Kearney, NE).

[2]Dietary electrolyte balance was determined by analyzing complete diets for Na, K, and Cl. Analyzed values were then used with the following equation to calculate dEB: [(Na × 434.98) + (K × 255.74) − (Cl × 282.06)].

Table 5. Chemical analysis of phase 2 diets (as-fed basis)[1]

	Dietary electrolyte balance (dEB, mEq/kg)			
Item	29	86	142	199
DM, %	88.16	88.71	88.71	88.36
CP, %	21.0	23.1	23.6	21.3
Ether extract, %	5.2	5.1	5.3	5.2
Na, %	0.33	0.35	0.30	0.30
K, %	0.93	0.94	1.06	1.00
Cl, %	1.11	1.13	0.85	0.77
Ca, %	1.33	1.57	1.40	1.59
P, %	0.68	0.86	0.87	0.82
dEB,[2] mEq/kg	68	74	162	169

[1]Chemical analysis of complete diets was analyzed by Ward Laboratories, Inc. (Kearney, NE).

[2]Dietary electrolyte balance was determined by analyzing complete diets for Na, K, and Cl. Analyzed values were then used with the following equation to calculate dEB: [(Na × 434.98) + (K × 255.74) − (Cl × 282.06)].

period), pigs that were previously fed low dEB diets had increased (linear, $P < 0.001$) ADG and marginally improved (quadratic, $P = 0.091$) G:F; however, no evidence for differences was detected for ADFI. For the overall nursery period (days 0 to 35), increasing dEB from days 0 to 21 increased (linear, $P < 0.001$) ADG and final BW, which was the result of increased (quadratic, $P = 0.030$) G:F and marginally greater (linear, $P = 0.077$) ADFI.

DISCUSSION

For the current experiment, dEB was determined by examining the interrelationship among the monovalent micromineral ions Na, K, and Cl: dEB, mEq/kg = (Na × 434.98) + (K × 255.74) – (Cl × 282.06) (Mongin, 1981). Previous literature examining the effects of dEB on pigs have generally demonstrated improvements in growth rate when dEB was increased with the NRC (2012) reporting the optimal electrolyte balance for pigs to be approximately 250 mEq/kg. However, there are discrepancies within the literature in regard to an optimal dEB range for growing pigs. Patience et al. (1987) conducted an experiment in which six levels (−85, 0, 100, 175, 277, and 341 mEq/kg) of dEB were fed to growing pigs (initially 15 kg BW) for 28 d with the supplemental calcium chloride included in the three low dEB diets and sodium bicarbonate used in the three high dEB diets. The authors reported that performance was optimized when pigs were fed a diet with a dEB of 175 mEq/kg. Similarly, Dersjant-Li et al. (2001) conducted an experiment in which pigs (initially 9 kg BW) were fed three dEB concentrations (−100, 200, and 500 mEq/kg) by including $CaCl_2$ in the low dEB diet and $NaHCO_3$ in the other two dEB diets. They observed greater ADG, ADFI, and G:F when pigs were fed diets with a dEB of 200 or 500 mEq/kg compared with −100 mEq/kg.

In contrast, Patience and Chaplin (1997) compared diets containing −20, 104, and 163 mEq/kg of dEB fed to pigs (initially 35 kg BW). For that study, supplemental salts $CaCl_2$, $NaHCO_3$, and $KHCO_3$ were included to alter dEB. Results indicated a tendency for improved growth when pigs were fed a dEB diet of −20 mEq/kg compared with pigs fed either 104 or 163 mEq/kg. Reason for the discrepancy between this and the aforementioned studies is unclear but may have been related to limit feeding. Feed intake was equalized across all treatments by feeding an amount that was equal to the pigs with the lowest feed intake compared with ad libitum feed intake allowed in other studies. Recently, Guzmán-Pino et al. (2015) conducted an experiment to determine the influence of dEB on growth performance of nursery pigs (initially 13 kg BW). In their study, four dEB concentrations (16, 133, 152, and 269 mEq/kg) were fed to pigs from 21 to 37 d after weaning with dEB altered by including $CaCl_2$ and $NaHCO_3$, respectively. The authors observed that increasing dEB decreased ADG and G:F when dEB exceeded 150 mEq/kg with a 48.7% improvement in ADG by decreasing dEB from 269 to 16 mEq/kg.

In this study, decreasing dEB in nursery diets resulted in a reduction in ADG and final BW, which was the result of marginally lower ADFI and poorer feed efficiency. A possible explanation for the lower feed intake in pigs fed the low dEB

Table 6. Effects of increasing dietary electrolyte balance on nursery pig performance[1]

	dEB[2], mEq/kg						
Days 0 to 8:	84	137	190	243			
Days 8 to 21:	29	86	142	199		Probability, *P*	
Days 21 to 35:	257				SEM	Linear	Quadratic
BW, kg							
Day 0	5.2	5.2	5.2	5.2	0.053	<0.753	<0.517
Day 8	5.62	5.60	5.70	5.80	0.043	<0.001	<0.038
Day 21	9.4	9.8	10.0	10.2	0.084	<0.001	<0.180
Day 35	15.6	15.7	15.9	16.0	0.119	<0.001	<0.547
Days 0 to 8							
ADG, g	53	48	57	74	4.9	<0.001	<0.001
ADFI, g	85	83	82	96	3.7	<0.008	<0.004
G:F	0.614	0.556	0.691	0.768	0.0378	<0.001	<0.049
Days 8 to 21							
ADG, g	282	314	322	335	5.4	<0.001	<0.022
ADFI, g	357	364	361	375	5.8	<0.001	<0.469
G:F	0.788	0.860	0.888	0.887	0.0093	<0.001	<0.001
Days 0 to 21							
ADG, g	193	211	219	235	3.3	<0.001	<0.807
ADFI, g	252	256	253	268	3.8	<0.003	<0.103
G:F	0.771	0.831	0.869	0.874	0.0084	<0.001	<0.001
Days 21 to 35							
ADG, g	440	424	423	415	4.7	<0.001	<0.376
ADFI, g	598	597	604	594	7.3	<0.891	<0.461
G:F	0.736	0.712	0.700	0.699	0.0067	<0.001	<0.091
Days 0 to 35							
ADG, g	290	295	299	306	3.4	<0.001	<0.736
ADFI, g	388	390	391	397	4.7	<0.077	<0.594
G:F	0.756	0.781	0.797	0.802	0.0052	<0.001	<0.030

[1]A total of 2,880 pigs (327 × 1,050; PIC, Hendersonville, TN; initial BW 5.2 kg) with 30 pigs per pen (60 pigs per feeder) and 12 replications (feeders) per treatment were used in a 35-d growth performance trial. All experimental diets were fed in two phases (days 0 to 8 and days 8 to 21) with a common diet fed from days 21 to 35.

[2]dEB = dietary electrolyte balance. It was calculated using the following formula: (Na × 434.98) + (K × 255.74) − (Cl × 282.06).

diet could be contributed to the $CaCl_2$ used to lower dEB. Yen et al. (1981) indicated that dietary $CaCl_2$ limited feed intake in pigs through Cl-induced metabolic acidosis. Furthermore, sensory tests using humans have indicated calcium chloride itself is perceived as producing a bitter and metallic off-flavor (Lawless et al., 2003, 2004). In addition, previous preference work conducted by Guzmán-Pino et al. (2015) examining a low (−16 mEq/kg; with $CaCl_2$) and high (388 mEq/kg; without $CaCl_2$) dEB diet indicated that pigs fed the low dEB diet had decreased preference compared with the high dEB diet. However, when similar diets were used in a growth performance trial, performance decreased when pigs were fed levels above 150 mEq/kg of the diet. Personal communication with the authors indicated that a similar unprotected $CaCl_2$ source, and the same equation was used to calculate the dEB as in our study. In addition, diets fed by Guzmán-Pino et al. (2015) were not analyzed for Na, K, and Cl, thus making it difficult to assess whether dEB concentrations were similar to estimated values. Another possible explanation includes starting the experimental diets at weaning (the study herein) vs. 21 d after weaning (Guzmán-Pino et al., 2015). Concentrations of Na, K, and Cl were generally lower in the diets used by Guzmán-Pino et al. (2015) than by Lei et al. (2017) or in the present study.

In agreement with the present study, Lei et al. (2017) reported that weanling pigs (initially 8 kg BW) fed diets with increasing dEB (0, 83, 166, and 250 mEq/kg) had improved ADG and ADFI. The authors altered dEB with the addition of $CaCl_2$ or $NaHCO_3$. Furthermore, increasing dEB resulted in improvements in apparent total tract digestibility of DM and N in pigs fed the high dEB diets (166 and 250 mEq/kg) compared with the low dEB diet (0 mEq/kg). Although digestibility measurements were not quantified in the current study, the improvement in feed efficiency as dEB increased could be a result of an improvement in nutrient digestibility.

It is worth noting that the majority of literatures discussed earlier, including the present study, only considered monovalent ions (Na, K, and Cl) in the calculation of dEB as it is most commonly used in swine diet formulation. More comprehensive estimation of dEB has been proposed that takes into account the contribution of divalent ions, such as Ca, Mg, S, and P. Future research is in need to investigate whether the discrepancies among studies may be a result of differences in dEB originating from divalent ions.

Moreover, interestingly, we observed a linear improvement in ADG and G:F during phase 3 (days 21 to 35) in pigs previously fed low dietary dEB. It is possible that pigs fed lower dietary dEB during days 0 to 21 with decreased growth performance had compensatory gain during the post-treatment period when dietary dEB was increased to 257 mEq/kg. However, further research is needed to verify this hypothesis.

In conclusion, results from this study indicate that increasing dEB up to 243 and 199 mEq/kg of diet from weaning to day 21 after weaning resulted in an increase in ADG and final BW, which was the result of a tendency for an increase in ADFI and G:F.

LITERATURE CITED

AOAC International. 2012. Official methods of analysis of AOAC Int. 19th ed. Gaithersburg (MD): Association of Official Analytical Chemists.

DeRouchey, J. M., J. D. Hancock, R. H. Hines, K. R. Cummings, D. J. Lee, C. A. Maloney, D. W. Dean, J. S. Park, and H. Cao. 2003. Effects of dietary electrolyte balance on the chemistry of blood and urine in lactating sows and sow litter performance. J. Anim. Sci. 81:3067–3074. doi:10.2527/2003.81123067x

Dersjant-Li, Y., H. Schulze, J. W. Schrama, J. A. Verreth, and M. W. Verstegen. 2001. Feed intake, growth, digestibility of dry matter and nitrogen in young pigs as affected by dietary cation-anion difference and supplementation of xylanase. J. Anim. Physiol. Anim. Nutr. (Berl) 85:101–109. doi:10.1046/j.1439-0396.2001.00307.x

Guzmán-Pino, S. A., D. Solà-Oriol, R. Davin, E. G. Manzanilla, and J. F. Pérez. 2015. Influence of dietary electrolyte balance on feed preference and growth performance of postweaned piglets. J. Anim. Sci. 93:2840–2848. doi:10.2527/jas.2014-8380

Haydon, K. D., J. W. West, and M. N. McCarter. 1990. Effect of dietary electrolyte balance on performance and blood parameters of growing-finishing swine fed in high ambient temperatures. J. Anim. Sci. 68:2400–2406. doi:10.2527/1990.6882400x

Lawless, H. T., F. Rapacki, J. Horne, and A. Hayes. 2003. The taste of calcium and magnesium salts and anionic modifications. Food Qual. Prefer. 14:319–325. doi:10.1016/S0950-3293(02)00128-3

Lawless, H. T., F. Rapacki, J. Horne, A. Hayes, and G. Wang. 2004. The taste of calcium chloride in mixtures with NaCl, sucrose, and citric acid. Food Qual. Prefer. 15:83–89: doi:10.1016/S0950-3293(03)00099-5

Lei, X. J., J. Y. Chung, J. H. Park, and I. H. Kim. 2017. Evaluation of different dietary electrolyte balance in weanling pigs diets. Anim. Feed. Sci. Technol. 226:98–102. doi:10.1016/j.anifeedsci.2017.02.014

Mongin, P. 1981. Recent advances in dietary anion-cation balance: applications in poultry. Proc. Nutr. Soc. 40:285–294. doi:10.1079/PNS19810045

Mushtaq, M. M. H., and T. N. Pasha. 2013. Electrolytes, dietary electrolyte balance and salts in broilers: an updated review on acid-base balance, blood and carcass characteristics. World Poult. Sci. J. 69:833–851. doi:10.1017/S0043933913000846

NRC. 2012. Nutrient requirements of swine. 11th ed. Washington (DC): National Academies Press.

NRC. 1998. Nutrient requirements of swine. 10th ed. Washington (DC): National Academies Press.

Patience, J. F., R. E. Austic, and R. D. Boyd. 1987. Effect of dietary electrolyte balance on growth and acid-base status in swine. J. Anim. Sci. 64:457–466. doi:10.2527/jas1987.642457x

Patience, J. F., and R. K. Chaplin. 1997. The relationship among dietary undetermined anion, acid-base balance, and nutrient metabolism in swine. J. Anim. Sci. 75:2445–2452. doi:10.2527/1997.7592445x

Yen, J. T., W. G. Pond, and R. L. Prior. 1981. Calcium chloride as a regulator of feed intake and weight gain in pigs. J. Anim. Sci. 52:778–782. doi:10.2527/jas1981.524778x