# Evaluation of different blends of medium-chain fatty acids, lactic acid, and monolaurin on nursery pig growth performance[1,2]

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**ABSTRACT:** A total of 710 pigs (Line 400 × 200, DNA, Columbus, net energy (NE)) were used in two experiments (Exp. 1: initially, 6.3 ± 0.05 kg; Exp. 2: initially, 6.8 ± 0.05 kg) to evaluate the effects of two medium-chain fatty acid (MCFA) based products on nursery pig growth performance. Following their arrival at the nursery facility, pigs were randomized to pens (five pigs per pen) and allowed a 4-d acclimation period. Thereafter, pens of pigs were blocked by initial weight and randomized to dietary treatment. In Exp. 1, the dietary treatments were a dose titration of: 0%, 0.5%, 1.0%, or 2.0% MCFA-based additive, as well as a diet including 1.0% MCFA from a 1:1:1 blend of C6:0, C8:0, and C10:0. In Exp.2, dietary treatments consisted of a basal diet containing no MCFA (control), the control diet with a 1.0% inclusion of four different blends of MCFA, lactic acid, and monolaurin or a diet with 1.0% added MCFA (a 1:1:1 blend of C6:0, C8:0, and C10:0). The four blends consisted of 50% C6:0, 20% lactic acid, and increasing levels of monolaurin (0%, 10%, 20%, and 30%) at the expense of C12:0 (30%, 20%, 10%, and 0%). Treatment diets were formulated and manufactured in two dietary phases. Data were analyzed as a randomized complete block design with pen as the experimental unit. In Exp. 1, overall (days 0–34), increasing CaptiSURE increased (linear, $P \leq 0.014$) average daily gain (ADG) and average daily feed intake (ADFI). Feed efficiency improved (quadratic, $P = 0.002$) with increasing CaptiSURE up to 1.0% of the diet with no benefit thereafter. There was no evidence for differences between pigs fed 1.0% CaptiSURE and pigs fed the 1.0% MCFA blend of C6:0, C8:0, and C10:0. In Exp. 2, overall (days 0–35), pigs fed the 1.0% 1:1:1 MCFA blend had increased ($P < 0.034$) ADFI and ADG resulting in 0.9 kg greater final weight ($P = 0.014$) compared with the control group. There was no evidence that the mean performance of pigs fed the four blends of MCFA, lactic acid, and monolaurin were different from the pigs fed the control diet. In summary, the addition of a 1.0% 1:1:1 blend of C6:0, C8:0, and C10:0 in nursery pig diets improved ADG, ADFI, and gain to feed ratio (G:F) compared with pigs fed the control diet. In addition, providing nursery pigs with the MCFA product CaptiSURE, up to 2% of the diet, resulted in linear improvements in ADG and ADFI. Altering the C12:0 to monolaurin ratio and adding lactic acid did not improve growth performance compared with pigs fed the control diet.

**Key words:** growth, lactic acid, medium-chain fatty acid, monolaurin, nursery pig

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## INTRODUCTION

Weaning is a complex transition phase during which pigs experience stress due to social, environmental, and dietary changes (Suiryanrayna and Ramana, 2015). During this time, the intestinal tract and immune system are not yet fully developed (Bailey et al., 2005). Because of these challenges, growth performance can be compromised (Xun et al., 2015). As a result, it has been typical to add feed-grade antimicrobials to weaned pig diets to improve growth performance (Suiryanrayna and Ramana, 2015). Numerous antibiotic alternatives are available; however, research surrounding the efficacy of these products is rarely comparable to that of antibiotics (Close, 2000; Doyle, 2001).

Organic acids, specifically medium-chain fatty acids (MCFA) and lactic acid, are receiving attention as feed additives in swine diets as they possess both bacteriostatic and bactericidal properties (Suiryanrayna and Ramana, 2015). Medium-chain fatty acids have been shown to reduce the infectivity of feed and ingredients containing porcine epidemic diarrhea virus (PEDV; Cochrane et al., 2016a), as well as improve growth performance in weaned pigs (Gebhardt et al., 2019). In addition, monoglycerides of MCFA, specifically C12:0 (monolaurin), have been shown to have stronger antibacterial property effects than other free fatty acids (Dansen, 2016). Previous research with organic acid blends containing lactic acid found reduced concentrations of *Salmonella* in feed (Cochrane et al., 2016b) and improvements in growth performance (Tsiloyiannis et al., 2001). Thus, commercial products are becoming available with proprietary blends of MCFA, as well as other ingredients. Because of differences in the response to feeding different free fatty acids and MCFA blends (Gebhardt et al., 2019), it is necessary to evaluate products and their impact on growth performance. Therefore, the objectives of these experiments were to evaluate commercial MCFA-blend feed additives on growth performance of nursery pigs.

## MATERIALS AND METHODS

### *General*

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. Both studies were conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. Each pen (1.22 × 1.22 m) contained a four-hole, dry self-feeder and cup waterer to provide ad libitum access to feed and water. Pens had tri-bar floors and allowed approximately 0.25 $m^2$/pig.

### *Animals*

Pigs were weaned at 21 d of age and transported to the research facility. Upon arrival, pigs were allotted randomly to pens of five based on their initial weight and allowed a 4-d acclimation period during which they were provided a commercial starter diet (pelleted) containing no feed-grade antimicrobials. On day 4 after weaning, considered day 0 in the trial, pens of pigs were blocked by weight and assigned randomly to the dietary treatments. In Exp. 1, a total of 350 pigs (Line 200 × 400; DNA, Columbus, net energy (NE); initially, 6.3 ± 0.05 kg) were used in a 34-d growth study, with five dietary treatments, and 14 pens per treatment. In Exp. 2, a total of 360 pigs (Line 200 × 400; DNA, Columbus, NE; initially, 6.8 ± 0.05 kg) were used in a 35-d growth study, with six dietary treatments, and 12 pens per treatment. In both experiments, pig weights and feed disappearance were measured every 7 d to determine ADG, ADFI, and G:F.

### *Diets*

The same control diet, to which feed additives were added, was used in both Exp. 1 and 2 (Table 1). Treatment diets were manufactured in two dietary phases and were formulated to meet or exceed NRC (2012) requirement estimates. In Exp. 1, treatments consisted of a basal diet with increasing amounts (0%, 0.5%, 1.0%, and 2.0%) of an MCFA-based additive composed of primarily C8:0 and C10:0 (CaptiSURE, Kemin Industries, Inc, Des Moines, IA), as well as a diet with 1.0% of added MCFA blend (Sigma Aldrich, St. Louis, MO) composed of a 1:1:1 ratio of C6:0, C8:0, and C10:0 that were guaranteed ≥98% purity. In Exp. 2, treatments consisted of a control diet containing no added MCFA, the control diet with 1.0% inclusion of four different blends of an MCFA, lactic acid, and monolaurin (monoglyceride form of C12:0) based additive (Tech Mix, LLC, Stewart, MN), as well as a diet with 1.0% of added MCFA blend (Sigma Aldrich, St. Louis, MO) composed of a 1:1:1 ratio of C6:0, C8:0, and C10:0. The four blends consisted of 50% C6:0, 20% lactic acid and increasing amounts of monolaurin (0%, 10%, 20%, and 30%) at the expense of C12:0 (30%, 20%, 10%, and 0%). In both experiments, all feed additives were included at the expense of soy oil on an equal weight basis in an attempt to keep diets similar in NE content.



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**Table 1.** Diet composition, Exp. 1 (as-fed basis)[a]

| Ingredient, % | Phase 1 | Phase 2 |
|---|---|---|
| Corn | 54.43 | 62.07 |
| Soybean meal, 46.5% CP | 26.42 | 31.63 |
| Whey powder | 10.00 | — |
| Enzymatically-treated soybean meal[b] | 2.50 | — |
| Soybean oil | 2.00 | 2.00 |
| Calcium carbonate | 0.95 | 1.00 |
| Monocalcium P (21% P) | 1.30 | 1.15 |
| Salt | 0.60 | 0.60 |
| L-Lysine HCl | 0.50 | 0.51 |
| DL-Methionine | 0.24 | 0.23 |
| L-Threonine | 0.21 | 0.21 |
| L-Tryptophan | 0.05 | 0.06 |
| L-Valine | 0.15 | 0.14 |
| Trace mineral[c] | 0.15 | 0.15 |
| Vitamin premix[d] | 0.25 | 0.25 |
| Phytase[e] | 0.02 | 0.02 |
| Zinc oxide | 0.25 | — |
| MCFA additive[f] | +/− | +/− |
| Total | 100 | 100 |
| Calculated analysis | | |
| Standardized ileal digestible (SID) amino acids, % | | |
| Lysine | 1.35 | 1.35 |
| Isoleucine:lysine | 55 | 55 |
| Leucine:lysine | 111 | 113 |
| Methionine:lysine | 37.4 | 37.3 |
| Methionine and cysteine:lysine | 58.1 | 58.1 |
| Threonine:lysine | 63.0 | 62.0 |
| Tryptophan:lysine | 20.1 | 20.3 |
| Valine:lysine | 70.2 | 70.1 |
| Total lysine, % | 1.48 | 1.49 |
| Net energy, kcal/kg | 2,529 | 2,511 |
| SID lysine:NE, g/Mcal | 5.69 | 5.63 |
| Crude protein, % | 20.6 | 21.1 |
| Calcium, % | 0.75 | 0.70 |
| Phosphorus, % | 0.68 | 0.63 |
| Available phosphorus, % | 0.51 | 0.42 |
| STTD P, % | 0.54 | 0.47 |

STTD P = standardized total tract digestible phosphorus.

[a]Phase 1 and 2 diets were fed from approximately 6.3 to 10.4 and 10.4 to 23.1 kg BW, respectively.

[b]HP 300 (Hamlet Protein, Findlay, OH).

[c]Provided per kilogram of premix: 22 g Mn from manganese oxide; 73 g Fe from iron sulfate; 73 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[d]Provided per kilogram of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin B3; 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.

[e]Ronozyme HiPhos 2700 (DSM Nutritional Products, Parsippany, NJ) providing 406.3 phytase units (FTU)/kg and an estimated release of 0.10% STTD P.

[f]MCFA included as a 1:1:1 blend of C6:0, C8:0, and C10:0 (Sigma Aldrich, St. Louis, MO; that were guaranteed ≥98% purity) were added in Exp. 1 and 2. In Exp. 1, CaptiSURE (Kemin Industries, Inc., Des Moines, IA), added at the expense of soybean oil. In Exp. 2, the blend of MCFA, lactic acid, and monolaurin-based additive (Tech Mix, LLC, Stewart, MN), added at the expense of soybean oil.

### *Chemical Analysis*

Diets were manufactured at the K-State O. H. Kruse Feed Technology Innovation Center, Manhattan, KS. Complete diet samples were taken from five feeders per dietary treatment four times throughout the study. Samples were stored at −20 °C until they were homogenized, subsampled, and submitted (Ward Laboratories, Inc., Kearney, NE) for analysis of dry matter (DM) [Association of Official Analytical Chemists (AOAC) 934.01 (AOAC, 2006)], crude protein (CP) (AOAC 990.03; AOAC, 2006), ADF (AOAC 978.10; AOAC, 2006), Ca (AOAC 965.14/985.01,AOAC, 2006), P (AOAC 965.17/985.01; A0OAC, 2006), and ether extract (AOAC 920.39 A; AOAC, 2006). In addition, in Exp. 1, MCFA concentration of C8:0 and C10:0 were analyzed (Kemin Industries, Inc., Des Moines, IA) and, in Exp. 2, MCFA concentration of C6:0, C8:0, C10:0, and C12:0 [American Oil Chemists' Society (AOCS) Ca 5a-40 (AOCS, 2017)] were analyzed (University of Missouri Experimental Station Chemical Laboratories, Columbia, MO).

### *Statistical Analysis*

In both experiments, data were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Weight block was included in the model as a random effect. In Exp.1, within the outcomes described above, linear and quadratic effects of increasing MCFA, as well as a preplanned pairwise contrast comparing MCFA (CaptiSURE) at 1.0% to the 1.0% 1:1:1 MCFA blend treatment, were evaluated. Linear and quadratic contrasts were developed using the Interactive matrix programming procedure of SAS, generating coefficients for unequally spaced treatments. In Exp. 2, estimated means and corresponding standard errors (SEM) were reported for cell means and pairwise comparisons were conducted on such means using a Tukey adjustment to prevent inflation of type I error due to multiple comparisons (Stroup, 2013). In addition, linear and quadratic effects of increasing monolaurin, as well as preplanned pairwise contrasts comparing the control group to the 1:1:1 MCFA blend and the mean of the four MCFA plus acidifier and monolaurin blends. Response variables were each fitted assuming a normal distribution, and residual assumptions were checked using standard diagnostics on



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residuals and were found to be reasonably met. All results were considered significant at $P \leq 0.05$ and marginally significant between $P > 0.05$ and $P \leq 0.10$.

## RESULTS

### *Chemical Analysis*

In Exp. 1 and 2, analysis of manufactured diets (Tables 2 and 3) resulted in values consistent with formulation, with the exception of ether extract. In Exp. 1, ether extract decreased as MCFA addition increased. Similarly, in Exp. 2, ether extract values for diets containing MCFA or the MCFA, acidifier, and monolaurin blends were lower compared with the control diet. Specifically, within the MCFA, acidifier, and monolaurin blends, as monolaurin increased (diets 1–4), ether extract increased but remained lower compared with the control diet. Recall that all MCFA products were added to diets at the expense of soybean oil to keep diets isocaloric in both experiments. Thus, we expected to see similar analyzed values for ether extract for all dietary treatments within each experiment; however, the results indicate a reduction in ether extract with the inclusion of MCFA. These findings are similar to analyzed values reported by Gebhardt et al. (2019). Ether extract was determined through an approved method from the AOCS (2017) utilizing high-temperature solvent extraction. These results suggest that the MCFA are not fully detected by this method of fat analysis. Furthermore, in Exp. 1, MCFA analysis results confirmed increasing amounts of C8:0 and C10:0 as CaptiSURE product inclusion increased, but results were lower than formulated values (Table 2). Similarly, in Exp. 2, analyzed MCFA results were less than formulated values for all dietary treatments containing MCFA (Table 3). These results also suggest that specific free fatty acids are likely not detected by ether extraction.

**Table 2.** Chemical analysis of experimental diets, Exp. 1 (as-fed basis)[a]

| | Added MCFA, % | | | | |
|---|---|---|---|---|---|
| | CaptiSURE[b] | | | | C6:0:C8:0:C10:0[c] |
| Analyzed composition, %[d] | 0 | 0.5 | 1.0 | 2.0 | 1.0 |
| Phase 1 | | | | | |
| DM | 89.73 | 89.97 | 89.67 | 89.19 | 90.09 |
| CP | 20.10 | 19.85 | 20.05 | 20.70 | 20.10 |
| ADF | 3.50 | 3.45 | 3.30 | 3.25 | 3.70 |
| Ether extract | 3.95 | 3.70 | 3.10 | 2.40 | 3.50 |
| Ca | 0.96 | 0.86 | 0.92 | 1.02 | 1.02 |
| P | 0.65 | 0.63 | 0.62 | 0.67 | 0.68 |
| Total MCFA[e] | — | 0.43 | 0.84 | 1.60 | 0.63 |
| Phase 2 | | | | | |
| DM | 89.46 | 89.04 | 89.29 | 88.54 | 89.62 |
| CP | 20.25 | 19.85 | 20.55 | 21.10 | 20.20 |
| ADF | 3.40 | 3.70 | 4.20 | 3.95 | 3.45 |
| Ether extract | 4.05 | 4.20 | 3.80 | 2.60 | 3.30 |
| Ca | 0.93 | 1.09 | 1.01 | 0.91 | 0.98 |
| P | 0.59 | 0.61 | 0.61 | 0.60 | 0.64 |
| Total MCFA[e] | — | 0.48 | 0.89 | 1.89 | 0.71 |

[a]Diets were fed from days 0 to 13 and 14 to 34 for phases 1 and 2, respectively.

[b]Kemin Industries, Inc. (Des Moines, IA).

[c]Consisted of a 1:1:1 blend of C6:0, C8:0, and C10:0 (Sigma Aldrich, St. Louis, MO).

[d]Complete diet samples were taken from five feeders per dietary treatment four times throughout the study. Samples were stored at −20 °C until they were homogenized, subsampled, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis and Kemin Industries, Inc. (Des Moines, IA) for MCFA analysis performed in duplicate. Reported values are average of duplicate analysis.

[e]Sum of analyzed C8:0 and C10:0 MCFA.

### *Exp. 1 Growth Performance*

From day 0 to 13 (dietary phase 1), increasing CaptiSURE increased (linear, $P < 0.001$) ADG (Table 4). Feed efficiency increased (linear, $P < 0.001$) up to 1.0% of the diet with marginal benefit observed thereafter. There was no evidence for differences in ADG or ADFI when comparing pigs fed 1.0% CaptiSURE and those fed the 1.0% 1:1:1 MCFA blend; however, there was marginal evidence ($P = 0.091$) for an increase in G:F for pigs consuming the 1.0% CaptiSURE.

From day 13 to 34 (dietary phase 2), pigs fed increasing CaptiSURE had increased (linear, $P < 0.001$) ADG and ADFI, as well as increased (quadratic, $P = 0.013$) G:F. Like days 0–13, G:F increased up to 1.0% CaptiSURE with no benefit observed at 2% of the diet. There was no evidence for differences in growth performance between pigs fed 1.0% CaptiSURE and those fed the 1.0% 1:1:1 MCFA blend.

Overall, ADG and ADFI were increased (linear, $P < 0.014$) with increasing CaptiSURE, resulting in a 1.8-kg difference in final body weight (BW) between the control group and pigs fed the 2.0% inclusion of CaptiSURE (linear, $P < 0.001$; Table 4). Feed efficiency increased from 0% to 1.0% CaptiSURE in the diet (quadratic, $P = 0.002$). Pigs fed 1.0% CaptiSURE and those fed the 1.0% 1:1:1 MCFA blend performed similarly, with no evidence for differences between the two treatment groups.



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**Table 3.** Chemical analysis of experimental diets, Exp. 2 (as-fed basis)[a]

| | | 1% MCFA, lactic acid and monolaurin blends[b] | | | | 1% MCFA[c] |
|---|---|---|---|---|---|---|
| Analyzed composition, %[d] | Control | 1 | 2 | 3 | 4 | C6:0:C8:0:C10:0 |
| Phase 1 | | | | | | |
| DM | 90.55 | 90.51 | 90.89 | 90.47 | 90.79 | 90.43 |
| CP | 20.10 | 20.50 | 20.10 | 20.80 | 20.75 | 20.70 |
| ADF | 1.80 | 1.75 | 1.70 | 1.95 | 1.95 | 1.95 |
| Ether extract | 3.85 | 3.40 | 3.70 | 3.70 | 3.75 | 3.80 |
| Ca | 0.86 | 0.79 | 0.85 | 0.90 | 0.96 | 0.82 |
| P | 0.64 | 0.66 | 0.61 | 0.71 | 0.70 | 0.67 |
| Total MCFA[e] | — | 0.45 | 0.42 | 0.43 | 0.33 | 0.51 |
| Phase 2 | | | | | | |
| DM | 89.97 | 89.64 | 90.04 | 89.99 | 89.89 | 89.68 |
| CP | 21.65 | 20.65 | 22.00 | 21.70 | 21.25 | 21.35 |
| ADF | 2.75 | 1.65 | 1.95 | 1.65 | 1.70 | 2.10 |
| Ether extract | 4.70 | 2.85 | 3.35 | 3.15 | 3.45 | 3.90 |
| Ca | 0.91 | 0.72 | 0.50 | 0.83 | 0.68 | 0.89 |
| P | 0.65 | 0.55 | 0.52 | 0.57 | 0.53 | 0.64 |
| Total MCFA[e] | — | 0.52 | 0.51 | 0.48 | 0.32 | 0.59 |

[a]Diets were fed from days 0 to 14 and 14 to 35 for phases 1 and 2, respectively.

[b]Consisted of a blend of C6:0, C12:0, lactic acid, and monolaurin (Tech Mix, LLC, Stewart, MN). The four blends consisted of 50% C6:0, 20% lactic acid, and increasing levels of monolaurin (0%, 10%, 20%, and 30%) at the expense of C12:0 (30%, 20%, 10%, and 0%) in products 1 through 4, respectively.

[c]Consisted of a 1:1:1 blend of C6:0, C8:0, and C10:0. (Sigma Aldrich, St. Louis, MO).

[d]Complete diet samples were taken from five feeders per dietary treatment four times throughout the study. Samples were stored at −20 °C until they were homogenized, subsampled, and submitted to Ward Laboratories, Inc. (Kearney, NE) for proximate analysis and University of Missouri Experimental Station Chemical Laboratories (Columbia, MO) for MCFA analysis performed in duplicate. Reported values are an average of duplicate analysis.

[e]Sum of analyzed C6:0, C8:0, C10:0, and C12:0 MCFA.

**Table 4.** Effect of MCFA-based additives on nursery pig growth performance (Exp. 1)[a]

| | Added MCFA, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | CaptiSURE[b] | | | | C6:0:C8:0:C10:0[c] | | Probability, < | | |
| Item | 0 | 0.5 | 1.0 | 2.0 | 1.0 | SEM | Linear[d] | Quadratic[d] | 1.0% CaptiSURE vs. 1.0% blend |
| BW, kg | | | | | | | | | |
| Day 0 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 0.05 | 0.778 | 0.927 | 0.911 |
| Day 13 | 9.9 | 10.2 | 10.4 | 10.4 | 10.2 | 0.14 | 0.001 | 0.062 | 0.288 |
| Day 34 | 21.8 | 22.8 | 23.2 | 23.6 | 23.1 | 0.33 | 0.001 | 0.089 | 0.838 |
| Days 0–13 | | | | | | | | | |
| ADG, g | 278 | 301 | 314 | 319 | 303 | 8.6 | 0.001 | 0.063 | 0.294 |
| ADFI, g | 338 | 364 | 353 | 360 | 352 | 9.9 | 0.149 | 0.211 | 0.912 |
| G:F, g/kg | 819 | 827 | 890 | 889 | 860 | 12.8 | 0.001 | 0.104 | 0.091 |
| Days 13–34 | | | | | | | | | |
| ADG, g | 567 | 600 | 605 | 627 | 615 | 10.6 | 0.001 | 0.273 | 0.446 |
| ADFI, g | 820 | 835 | 839 | 865 | 853 | 14.9 | 0.013 | 0.974 | 0.440 |
| G:F, g/kg | 692 | 719 | 721 | 725 | 722 | 5.9 | 0.001 | 0.013 | 0.953 |
| Days 0–34 | | | | | | | | | |
| ADG, g | 455 | 486 | 493 | 509 | 496 | 9.0 | 0.001 | 0.127 | 0.779 |
| ADFI, g | 634 | 655 | 652 | 671 | 662 | 12.3 | 0.014 | 0.693 | 0.494 |
| G:F, g/kg | 718 | 742 | 756 | 758 | 750 | 5.5 | 0.001 | 0.002 | 0.360 |

[a]A total of 350 pigs (DNA 400 × 200; initial BW = 6.3 kg) were used in a 34-d experiment with five pigs per pen and 14 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 4 d postweaning, and then placed on experimental diets.

[b]Kemin Industries, Inc. (Des Moines, IA).

[c]Consisted of a 1:1:1 blend of C6:0, C8:0, and C10:0 (Sigma Aldrich, St. Louis, MO).

[d]Linear and quadratic contrast statements include treatments with CaptiSURE (Kemin Industries, Inc, Des Moines, IA) MCFA.



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**Table 5.** Effect of MCFA on nursery pig growth performance (Exp. 2)[a]

| Item | Control | 1% MCFA, lactic acid and monolaurin blends[b] | | | | 1% MCFA[c] | SEM | Probability, $P <$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | C6:0:C8:0:C10:0 | | Control vs. 1% C6:0:C8:0:C10:0 | Control vs. blends[d] | Linear[e] | Quadratic[f] |
| BW, kg | | | | | | | | | | | |
| Day 0 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 0.05 | 0.918 | 0.943 | 0.730 | 0.303 |
| Day 14 | 9.9 | 10.1 | 10.2 | 10.2 | 10.3 | 10.4 | 0.17 | 0.042 | 0.132 | 0.355 | 0.802 |
| Day 35 | 21.6 | 21.8 | 22.0 | 22.1 | 22.2 | 22.5 | 0.28 | 0.014 | 0.134 | 0.267 | 0.840 |
| Days 0–14 | | | | | | | | | | | |
| ADG, g | 225 | 239 | 240 | 246 | 254 | 259 | 11.2 | 0.037 | 0.127 | 0.304 | 0.750 |
| ADFI, g | 286 | 280 | 283 | 287 | 300 | 305 | 11.3 | 0.223 | 0.887 | 0.204 | 0.676 |
| G:F, g/kg | 788[b] | 852[ab] | 847[ab] | 855[a] | 844[ab] | 846[ab] | 16.2 | 0.013 | 0.001 | 0.838 | 0.868 |
| Days 14–35 | | | | | | | | | | | |
| ADG, g | 554 | 555 | 565 | 564 | 565 | 577 | 8.9 | 0.057 | 0.366 | 0.402 | 0.600 |
| ADFI, g | 772 | 785 | 793 | 792 | 794 | 820 | 14.0 | 0.015 | 0.206 | 0.641 | 0.822 |
| G:F, g/kg | 719 | 707 | 713 | 713 | 713 | 705 | 7.7 | 0.230 | 0.416 | 0.645 | 0.686 |
| Days 0–35 | | | | | | | | | | | |
| ADG, g | 422 | 427 | 435 | 437 | 441 | 450 | 7.7 | 0.014 | 0.149 | 0.202 | 0.796 |
| ADFI, g | 577 | 581 | 588 | 590 | 597 | 614 | 11.9 | 0.034 | 0.382 | 0.359 | 0.932 |
| G:F, g/kg | 733 | 736 | 739 | 741 | 740 | 734 | 6.56 | 0.932 | 0.422 | 0.628 | 0.713 |

[a]A total of 360 pigs (DNA 400 × 200; initial BW = 6.8 kg) were used in a 35-d experiment with five pigs per pen and 12 pens per treatment. Pigs were weaned at approximately 21 d, fed a common starter diet for 4 d postweaning, and then placed on experimental diets. Values with different superscripts within a row differ, $P < 0.05$.

[b]Consisted of a blend of C6:0, C12:0, lactic acid, and monolaurin (Tech Mix, LLC, Stewart, MN). The four blends consisted of 50% C6:0, 20% lactic acid, and increasing levels of monolaurin (0%, 10%, 20%, and 30%) at the expense of C12:0 (30%, 20%, 10%, and 0%) in products 1 through 4, respectively.

[c]Consisted of a 1:1:1 blend of C6:0, C8:0, and C10:0 (Sigma Aldrich, St. Louis, MO).

[d]Contrast comparing the control group to the average of the four diets, including different blends of MCFA, lactic acid, and monolaurin blends included at 1.0% of the diet.

[e]Linear effects of increasing monolaurin, at the expense of C12:0, within the 1% MCFA, lactic acid, and monolaurin blend.

[f]Quadratic effects of increasing monolaurin, at the expense of C12:0, within the 1% MCFA, lactic acid, and monolaurin blend.

### *Exp. 2 Growth Performance*

From day 0 to 14 (dietary phase 1), pigs fed the 1.0% 1:1:1 MCFA blend had increased ($P = 0.037$) ADG compared with the control group (Table 5). Feed efficiency was improved ($P < 0.013$) with the addition of 1:1:1 MCFA blend and the MCFA, acidifier, and monolaurin blends. From day 14 to 35 (dietary phase 2), pigs fed the 1.0% 1:1:1 MCFA blend had increased ($P < 0.057$) ADFI and, subsequently, ADG compared with the control group.

Overall, ADFI and ADG were increased ($P < 0.034$) when the 1.0% 1:1:1 MCFA blend was included in the diet compared with the control group. This increase in ADG resulted in pigs fed the 1.0% 1:1:1 MCFA blend being 0.9 kg heavier ($P = 0.014$) than the control group on day 35 of the study. There was no evidence for differences between the control group and the 1.0% inclusion of the MCFA, acidifier, and monolaurin blends. In addition, there was no evidence for linear or quadratic effects of increasing monolaurin on nursery pig performance.

## DISCUSSION

For the young weaned pig, postweaning is a critical phase in life often resulting in a reduction in feed intake, causing energy deficiency, changes in the intestinal morphology, reduced absorptive capacity, impaired immune reactivity, and changes in intestinal microbiota (Pluske et al., 1997; Konstantinov and Smidt, 2006; Lallés et al., 2007). Thus, research involving feed additives acting as antibiotic replacements for weaned pigs has been extensive in recent years, with promising results in the use of organic acids (Liu et al., 2018).

Medium-chain fatty acids are classified as a type of organic acid that can be considered for use as antibiotic replacers (Decuypere and Dierick, 2003). Medium-chain fatty acids are defined as saturated fatty acids with 6 (caproic acid, C6:0), 8 (caprylic acid, C8:0), 10 (capric acid, C10:0), or 12 (lauric acid, C12:0) carbon atoms. They are found naturally as medium-chain triglycerides (MCT) in milk fat and various feed ingredients, including coconut and palm oils (Rossi et al., 2010); however, MCFA



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as feed additives for swine are commercially available as single MCFA or blends of MCFA. Previous research by Cochrane et al. (2016a, 2016b) observed that the inclusion of an MCFA blend (1:1:1 ratio of C6:0, C8:0, and C10:0) at 1.0% and 2.0% of the diet decreased the presence of *Salmonella* Typimurium ATCC 14028 and enhanced RNA degradation of PEDV in swine feed and ingredients. They also observed similar results when testing individual fatty acids (C6:0, C8:0, and C10:0) at 0.66% of the diet (Cochrane et al., 2017). Because of these desirable antibacterial and antiviral effects, further research by Gebhardt et al. (2019) was conducted to determine the effects on growth performance when feeding nursery pigs diets containing these blends of MCFA, as well as individual fatty acids. Gebhardt et al. (2019) reported that ADG, ADFI, and G:F increased linearly as MCFA (1:1:1 ratio among C6:0, C8:0, and C10:0) increased up to 1.5% of the diet and the addition of individual fatty acids at 0.5% (C6:0, C8:0, or C10:0) resulted in an improvement in ADG and G:F.

In Exp. 1, our results were similar to Gebhardt et al. (2019) in that we observed that feeding up to 2% CaptiSURE and 1.0% of the 1:1:1 MCFA blend resulted in increased ADG, ADFI, and G:F compared with the control diet. In Exp. 2, pigs fed 1.0% inclusion of the 1:1:1 MCFA blend performed much like those in Exp. 1 and had improved growth performance compared with pigs fed the control diet. These results are consistent with previous literature evaluating the effects of dietary additions of C6:0, C8:0, and C10:0 on growth performance (Zentek et al., 2011; Hanczakowska et al., 2017; Cochrane, 2018). When evaluating individual fatty acids, previous research with C6:0 at 0.5% inclusion showed an improvement in growth performance (Gebhardt et al., 2019); however, in Exp. 2, these benefits were not observed. The 1.0% inclusion of the MCFA blend used in Exp. 2 contained 50% C6:0 and varying amounts of C12:0 and its monoglyceride, monolaurin. Interestingly, Cochrane et al. (2017) reported enhanced RNA degradation of PEDV in swine feed and ingredients for C6:0, C8:0, and C10:0 but not for C12:0. Thus, the MCFA blends included in Exp. 2 with C6:0, C12:0, and monolaurin might be less effective compared with MCFA blends of C6:0, C8:0, and C10:0. Specifically, the inclusion of C8:0 might have a larger impact on growth performance than other MCFA (Cochrane, 2018).

Uncertainty still exists about the growth-promoting mechanisms of MCFA beyond reducing bacterial or viral load in complete feed (Cochrane et al., 2016a, 2016b, 2017). It is speculated that the antibacterial and antiviral properties of MCFA may reduce the bacterial population within the gut and enhance nutrient absorption in the small intestines, resulting in a healthier pig (Hanczakowska et al., 2017). In a review by Zentek et al. (2011), the authors suggest that the use of MCFA in swine diets alter the acidification in the stomach of the animal and provide desirable antibacterial effects. Newly weaned pigs appear to have a high capacity to oxidize fatty acids, and MCFA can be used directly by the enterocytes in the upper small intestine for efficient energy production, as well as to help support the integrity of the intestinal tissue (Zentek et al., 2011). Specifically, MCFA are thought to work by lowering intestinal pH, stimulating enzyme secretion, and inhibiting pathogenic bacteria, thereby improving nutrient digestibility and retention (Baustadt, 1993; Decuypere and Dierick, 2003; Papatsiros et al., 2012; Upadhaya, 2018). Although research in this area is inconsistent, previous research has also indicated that MCFA can influence epithelial function (villus length and crypt depth) in the upper small intestine, possibly increasing the uptake and utilization of nutrients through the intestinal wall (Dierick et al., 2004; Hanczakowska et al., 2011; Chwen et al., 2013). However, others have found no evidence for differences in intestinal morphology when feeding MCFA (Biagi et al., 2006; Hanczakowska et al., 2016; Ferrara et al., 2017).

In addition to supplementing swine diets with MCFA, lactic acid and monolaurin have been considered as antibiotic replacements. Much like MCFA, lactic acid has strong antimicrobial properties and reduces gastric pH, improves pancreatic secretions that increase nutrient digestibility, and reduces the production of harmful microbes, thereby improving pig growth performance (Thompson and Lawrence, 1981). In general, the antimicrobial impact of lactic acid is directed against gram-negative bacteria (Suiryanrayna and Ramana, 2015), whereas most MCFA, specifically C12:0 and its monoglyceride ester monolaurin, target gram-positive bacteria (Ruzin and Novick, 2000; Dansen, 2016). Therefore, the theory behind the development of the MCFA product used in Exp. 2 was that by creating blends of MCFA, other organic acids, and MCFA monoglycerides, different populations of bacteria within the gut would be targeted, thereby further reducing microbial populations that may negatively affect pig growth.

In Exp. 2, when pigs consumed the added 1.0% of MCFA, acidifier, and monolaurin blends, we



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observed no evidence for differences in growth performance compared to the control group. These results are similar to those of Zentek et al. (2013) where the authors fed nursery pigs diets with or without 1.05% organic acid product (31.2% lactic acid and 39.8% fumaric acid, with silicium dioxide as a carrier material) and with or without 0.3% MCFA (1:1 ratio C8:0 and C10:0) and found no evidence for differences in ADG, ADFI, or G:F among dietary treatments. However, these results are in disagreement with previous literature where different combinations of organic acids and MCFA had positive effects on growth performance, as well as nutrient digestibility in pigs (Hanczakowska et al., 2013; Upadhaya et al., 2014; Kuang et al., 2015; Long et al., 2018). Inconsistencies in literature surrounding the effects of MCFA and MCFA blends on nursery pig growth performance can be attributed to many factors, including inclusion level, type of MCFA or blend, basal diet characteristics, and health status of the animal (Geng et al., 2016). Pigs in both studies would be considered high health and were porcine respiratory and reproductive syndrome virus free.

The effect MCFA have on feed intake is a specific area of interest. Previous research agrees that free MCFA can produce strong goat-like odors and often lead to a reduction in feed intake (Cera et al., 1989; Timmermann, 1993; Molimard et al., 1997). In addition, MCFA can induce the release of cholecystokinin, which can negatively influence the feeling of satiety and lower feed intake (Mabayo et al., 1992; Dierick et al., 2002). However, research in this area is inconsistent. In both experiments herein, free MCFA C6:0, C8:0, and C10:0 produced strong odors both in pure form and in the complete feed, as well as the blended products; however, ADFI increased linearly as added MCFA increased. It is important to note that, in both experiments, pigs were allowed a 4-d adaptation period during which a common starter diet was fed to encourage feed intake prior to the start of the trial. We do not have evidence that starting weanling pigs on diets containing MCFA would either enhance or decrease feed intake.

In conclusion, the addition of 1.0% 1:1:1 blend of C6:0, C8:0, and C10:0 in nursery pig diets increased ADG, ADFI, and G:F compared with control-fed pigs. Providing nursery pigs with CaptiSURE, an MCFA-based feed additive made up of predominantly C8:0 and C10:0 fatty acids, improved ADG, ADFI, and G:F up to 2.0% of the diet. Altering the blend of individual C:12 to monolaurin and adding lactic acid showed similar nursery pig growth performance to those fed the control diet. Additional research is warranted to understand if a blend of MCFA, acidifiers, and monoglycerides can be created to achieve similar benefits in growth performance shown from the 1.0% 1:1:1 MCFA blend and provide a beneficial economic return.

*Conflict of interest statement*. D.J.M. is an employee of Kemin Industries, the manufacturer of one of the products used in these studies. D.J.M. and A.M.J. are employees of Tech Mix, LLC, the manufacturer of one of the products used in these experiments.

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