NPB FINAL RESEARCH GRANT REPORT FORMAT

Optimizing late finishing pig feed efficiency, carcass yield, and economic return
NPB Project #21-102
PI – Joel DeRouchey
Kansas State University
11-30-22

Industry Summary:
Optimizing late finishing pig feed efficiency, carcass traits, and economic return through feeding practices is essential for the sustainability of pork production. This multi-facetted project focused on: 1) development of a meta-analysis of feed additives for finishing pigs; 2) based on the findings of the feed additive review, L-Carnitine and 2 acidifiers, sodium diformate and benzoic acid were identified as products to further test and studies were conducted under commercial finishing conditions; 3) evaluating extruded expelled soybean meal that is higher in fat (energy) then regular soybean meal; and 4) evaluation of in-barn feeder management prior to marketing to reduce feed cost, improve carcass feed efficiency and yield and economic return.

The meta-analysis of feed additives for finishing pigs involved evaluating published research using 805 comparisons for ADG and 773 comparisons for feed efficiency. The feed additives of interest were acidifiers, betaine, Cr, conjugated linoleic acid (CLA), Cu, direct-fed microbials (DFM), carbohydrases, proteases, phytases, multi-enzymes (combinations of carbohydrases, proteases, or phytases), essential oils (EO), L-carnitine, yeasts, and Zn. Ultimately acidifiers, betaine, CLA, direct fed microbials, multi-enzyme blends, L-carnitine, and yeast products were the feed additives identified with the greatest opportunity for improving finishing pig feed efficiency.

Of the additives with the highest opportunity for success, we chose to test 2 acidifiers, benzioic acid and sodium diformate, and the additive L-Carnitine under commercial field conditions to help validate and bring increased confidence for swine producers in decision making. Also, the use of extruded expelled soybean meal (EESBM) has gained interest due to the high cost of added fat as a potential means to increase diet energy and improve feed efficiency. Across all three trials, 6,157 finishing pigs in commercial research facilities were used. The findings revealed that feeding increasing levels of sodium diformate in commercial finishing pigs improved ADG and ADFI after approximately 180 lb of body weight but not before. However, the increased feed cost was not offset by the increased revenue, thus it was not economical to feed in this study. Similarly, the addition of benzoic acid or the use of EESBM improved finishing pig feed efficiency but did not improve economics due to the increased feed cost being greater than the returned benefit. Finally, feeding L-Carnitine improved growth in the grower period (58 to 104 lb body weight) but not finishing period. Thus, all four ingredients tested under commercial conditions did improve gain or feed efficiency, but more refinement is needed to determine the correct feeding duration (weight range) or inclusion rate that will result in the greatest benefit in performance and economical return.

Finally, when removing feed prior to marketing, this research, the first of its kind, showed limited benefits to the extra labor and time required to close all feeders from

feed delivery 12 or 24 hours prior to harvest for finishing pigs topped prior to final barn marketing event. Additionally, carcass yield was greater for those with 12 h of feed withdrawal before harvest compared to those with 24 h of feed withdrawal prior to harvest at barn dumping, which contrasted with previous research. As expected, pigs with a longer time of feed withdrawal had reduced feed consumption and feed cost/pig on the day of marketing.

Dr. Joel DeRouchey
Kansas State University
Department of Animal Sciences and Industry
Extension Swine Specialist
222 Weber Hall
Manhattan, KS 66506
jderouch@ksu.edu
phone - 785-532-2280
www.ksuswine.org

Key Findings:

- In a comprehensive review of the literature, acidifiers, betaine, CLA, direct fed microbials, multi-enzyme blends, L-carnitine, and yeast products were the feed additives identified with the greatest opportunity for improving finishing pig feed efficiency. However, inclusion level and feeding duration needs further evaluation in order to define the best performance and profitability.
- Feeding L-Carnitine to commercial finishing pigs had improved ADG and ADFI in the early grow-finishing phase (58 to 104 lb body weight). However, this effect was not detectable at marketing. Although pigs fed L-Carnitine had carcasses that averaged 2 lb heavier, this improvement was not statistically different.
- For acidifiers, feeding increasing levels of sodium diformate to commercial finishing pigs improved ADG and ADFI after d 60 in the grow-finish period (>180 lb body weight). However, due to the increased feed cost, the improved growth performance did not offset the increased diet costs and therefore it is currently not economical to feed sodium diformate throughout the entire grow-finish period. Therefore, investigating the addition of sodium diformate only in the late finisher should be considered to understand if pigs will have similar improvements in growth performance while reducing overall feed cost. Similarly, feeding benzoic acid in finishing improved feed efficiency but did not improve income over feed cost.
- Feeding extruded expelled soybean meal as a replacement for conventional soybean meal in commercial finishing pigs improved feed efficiency, but due to increased feed cost without influencing gain, it was less economical as measured by income over feed cost.
- When removing feed prior to marketing, carcass yield was greater for those with 12 h of feed withdrawal before harvest compared to those with 24 h of feed withdrawal prior to harvest at the barn dump, which contrasted with previous research. Also, as expected, pigs with a longer time of feed withdrawal had reduced feed consumption and feed cost/pig on the day of marketing.

Keywords: feed efficiency, feed additives, feeder adjustment, finishing pigs, carcass traits, growth

Scientific Abstract:

A meta-analysis of feed additives that could influence finishing pig's growth and carcass performance and feed efficiency was conducted and considered the following additives: acidifiers, betaine, Cr, conjugated linoleic acid (CLA), Cu, direct-fed microbials (DFM), carbohydrases, proteases, phytases, multi-enzymes, essential oils (EO), L-carnitine, yeasts, and Zn. Research articles were collected from online research databases. Inclusion and exclusion criteria were utilized to select qualified research articles. The percentage difference for each response variable between the treatment and control group was calculated and summarized to determine the expected magnitude of effect. Most of the results showed positive outcomes for each feed additive; however, the magnitude of improvement varied, and most were not statistically significant. For ADG, DFM, Cu, L-carnitine, and multi-enzymes showed relatively large and positive effects across a reasonable number of research articles. Acidifiers, betaine, CLA, multi-enzymes, DFM, L-carnitine, and yeasts showed relatively large and positive effects on improving G:F. Moreover, except for betaine, Cr, CLA, and L-carnitine, most feed additives showed little and non-significant effects on carcass characteristics. In the first of 4 growth experiments, 1,833 mixed-sex growing-finishing pigs (initially 58.5 ± 1.62 lb) were used in a 112-d growth trial to determine the effects of adding L-Carnitine throughout the entire grow-finishing period or just the last 28 d before marketing on growth performance and carcass characteristics. There were 26 replicate pens per treatment and 20 (group 1) or 27 (group 2) pigs per pen in a completely randomized design. There were three treatment diets: 1) control with no added L-Carnitine; 2) diets containing 50 ppm of L-Carnitine for the entire trial; and 3) control diet until d 84 and then a diet containing 50 ppm of L-Carnitine fed until marketing. In the first 28 d, pigs fed L-Carnitine had greater ($P < 0.002$) BW, ADG, and ADFI and similar F/G ($P = 0.459$) as those fed the control diet. From d 0 to 84, pigs fed L-Carnitine had a tendency ($P = 0.052$) for greater ADFI, but there was no evidence ($P > 0.14$) of differences for ADG, F/G, removals, or mortalities. From d 85 to market and overall, there was no evidence of differences ($P > 0.22$) in growth. For Exp. 2, 2,200 pigs (initially 53.4 ± 0.66 lb) were used in a 117-d growth trial to evaluate dietary sodium diformate level on grow-finish pig's growth and carcass characteristics. Pens of pigs (25 pigs per pen) were randomly assigned to 1 of 4 dietary treatments in a randomized complete block design with 22 replicates per treatment. Dietary treatments contained 0, 0.25, 0.50, or 0.75% sodium diformate (Formi NDF; ADDCON Nordic AS, Porsgrunn, Norway). Overall (d 0 to 117), pigs fed increasing sodium diformate had increased (linear, $P < 0.01$) ADG and a tendency for increased (linear, $P = 0.075$) ADFI; however, there was no evidence for differences ($P > 0.05$) in feed efficiency. For Exp. 3 2,162 pigs (initially 69.2 ± 4.9 lb) were used in a 109-d finishing trial to evaluate the effects of extruded-expelled soybean meal (EESBM) and benzoic acid on growth, carcass characteristics, and carcass iodine value. Pigs were randomly allotted to 1 of 4 treatments with 27 to 28 pigs per pen and 20 pens per treatment. Dietary treatments were arranged in a 2 × 2 factorial with main effects of soybean meal source and benzoic acid. Diets contained either conventional soybean meal (SBM) or extruded-expelled soybean meal (EESBM; Lester Feed and Grain, Lester, IA) with or without 0.25% benzoic acid (VevoVitall, DSM Nutrition; Parsippany, NJ). The EESBM was analyzed to be 43.2% CP and 7.73% fat (acid hydrolysis). Overall (d 0 to

109), there were no interactions between soybean meal source and benzoic acid addition. There was a main effect of soybean meal source where pigs fed conventional SBM had greater ($P = 0.01$) ADFI compared to pigs fed EESBM without influencing ADG, resulting in poorer ($P < 0.001$) F/G. Also, pigs fed diets with benzoic acid had lower ($P = 0.02$) ADFI without influencing ADG compared to pigs fed diets without benzoic acid, resulting in pigs fed benzoic acid having improved ($P = 0.01$) F/G. In Exp. 4, 695 finishing pigs (initially 242.7 ± 1.36 lb) were used in a 14-d trial to determine the effects of feed withdrawal before the first topping and final marketing event on carcass weight, carcass yield, and economics. Pens of pigs were assigned to 1 of 3 treatments in a randomized complete block design. There were 24 pens per treatment and 9 or 10 pigs per pen. Treatments consisted of none, 6, or 12 h of feeder closure prior to loading pigs on the truck at both the first (2 weeks before final marketing) and final marketing to achieve approximately 12, 18, and 24 h of feed withdrawal prior to harvest at the processing plant. Pig BW at time of loadout, with 24-h of feed withdrawal prior to harvest were lighter ($P < 0.05$) than those with only 12 h of feed withdrawal both at first marketing event and the last. Pigs that had access to feed (12 h withdrawal prior to harvest) gained weight during the marketing day, while pigs with 18 or 24 h of feed withdrawal lost weight. For carcass characteristics, pigs at final marketing with 12 h feed withdrawal prior to harvest had increased ($P < 0.05$) HCW compared to those with 24 h feed withdrawal. There was a tendency ($P = 0.055$) for a treatment effect with pigs achieving 12 h feed withdrawal prior to harvest having a 1.1 lb heavier HCW than those with 24 h feed withdrawal. When evaluating carcass yield, using live weights for all pigs 24 h prior to harvest, pigs in the final marketing group with 12 h of feed withdrawal prior to harvest had greater yield ($P < 0.05$) than those marketed with 24 h of feed withdrawal. However, when evaluating carcass yield using live weights 12 h prior to harvest for the final marketing and overall, pigs marketed with 24 h of feed withdrawal had greater yield ($P < 0.05$) than the other two treatments. There were no differences in backfat, loin depth, and lean % between treatments. Feed consumed on the day of marketing and feed cost per pig were increased ($P < 0.05$) for pigs marketed with 12 or 18 h of feed withdrawal prior to harvest compared to those with 24 h feed withdrawal.

Introduction:

Optimizing late finishing pig feed efficiency, carcass traits, and economic return though feeding practices is essential for the sustainability of pork production. However, to accomplish this task, it takes considerable effort in understanding feed management and available feed additives in the marketplace to have such an impact. While numerous research trials are available, a recent and comprehensive review of feed additives used in finishing diets has not been summarized. Through this work a comprehensive summary is now compiled for producer and nutritionist utilization. Subsequently, promising additives based on this review were then further researched under commercial conditions to help validate and bring confidence for swine producers in decision making. Also, feeder management prior to marketing has been a method to reduce feed cost and increase carcass yield but this practice has not been evaluated for pigs that are topped prior to final marketing. Thus, research is needed to determine if this could be practical with quick adjust feeders to close off feed flow for pigs being topped for marketing in finishing barns.

Objectives:
The primary objective of this project was to improve industry-wide knowledge about factors affecting late finishing pig feed efficiency, growth performance, and their economic impact on producer profitability. To accomplish this overall objective, the specific high impact areas studied were:

1. Literature review (meta-analysis) of finishing feed additives to identify those with the highest likelihood to improve feed efficiency, growth performance, and carcass characteristics.
2. Based on information generated from the literature review, feed additives with the highest likelihood of success were selected and tested in a commercial environment:
    a. Determine the effects of adding L-Carnitine throughout the entire grow-finishing period or just 28 d prior to marketing on growth performance and carcass characteristics of pigs raised in a commercial environment.
    b. Determine the effects of increasing levels of sodium diformate in grow-finish diets on growth performance and carcass characteristics.
3. Determine the effects of extruded expelled soybean meal and benzoic acid on finishing pig growth, carcass traits, carcass IV and economics.
4. Evaluation of in-barn feeder management prior to marketing to reduce feed cost, improve carcass yield and economic return.

Materials & Methods: Objective 1
Data source
The online article databases used for this literature review were the International System for Agricultural Science and Technology (AGRIS), Centre for Agriculture and Bioscience International (CABI; CAB Direct), Pork Checkoff research, PubMed, and Scopus. Articles were identified using the following terms: pig, swine, barrow, or gilt with the name of the feed additive of interest. The feed additives of interest were acidifiers, betaine, Cr, conjugated linoleic acid (CLA), Cu, direct-fed microbials (DFM), carbohydrases, proteases, phytases, multi-enzymes (combinations of carbohydrases, proteases, or phytases), essential oils (EO), L-carnitine, yeasts, and Zn. This literature review did not include ractopamine (RAC) because of the global trend of removing RAC in grow-finish pig diets. The language of the articles was limited to English, and the article types were limited to research articles and university research reports.
Inclusion and exclusion criteria
Research articles were included if they met the following criteria: 1) the study was an original randomized controlled study; 2) the study had a control group fed a basal diet without the feed additive of interest and treatment groups with the feed additive added to the basal diet with other nutrient values similar to the control; 3) control and treatment pigs had to have a similar starting live body weight over 7 kg (post-weaning), and an end point above 80 kg live body weight with an identical (fix-time study) or similar (fix-weight study) experimental period; 4) the study reported either the growth performance (BW, ADG, ADFI, G:F), carcass characteristics [e.g., carcass weight, percent carcass yield, backfat thickness (BF), loin muscle area (LMA), loin muscle depth (LD), percentage lean] or both criteria with statistical analysis. The

exclusion criteria were: 1) duplicate search results; 2) data duplication between different research articles; 3) the article did not provide numeric values of the results; or 4) the original full text of the article could not be found.

Data extraction and analysis

Article information, treatment design, response variables, and statistical results were extracted from the selected articles. Article information included authors, published journal, article type, title, published year, and the location of the study. Treatment design included the feed additive used, the form of the additive, feed additive inclusion level, duration of the study, the first 2 major ingredients in the diet (e.g., corn-soybean meal, barley-wheat), pig breed, sex, housing type (individual or group pen), and initial BW. Response variables included final BW, ADG, ADFI, G:F, carcass weight, BF, percentage lean, and LMA/LD. Statistical results included the standard error of the mean (SEM) of the response of interest and the *P*-value of the response of interest compared to the control. Because the reported values of BF vary on the sampling locations, if the location was reported, the priority sequence of extracted value was average BF, 10^{th} rib BF, last rib BF, loin BF, and other locations. If the location was not reported, the value was extracted as listed in the article regardless of the location. Because of the similarity between LMA and LD, both values were extracted for the same category. If both values were reported, LMA was prioritized over LD. The extracted data of each treatment group was entered into the database as a row of data.

The relative difference of the response between the treatment group and the control was calculated as the percentage of difference and defined as a comparison in this literature review. The determination of significance, *P*-value, and response value were based on the study design and statistical analysis. The significance of each comparison was categorized as significant if the reported *P*-value was below or at 0.05 ($P \leq 0.05$). The comparisons were categorized as tendency if the reported *P*-value was between 0.05 and 0.10 ($0.05 < P \leq 0.10$) and as nonsignificant if the reported *P*-value was above 0.10 ($P > 0.10$). For studies that only reported whether the *P*-value was below or above 0.05 and it cannot be determined whether there was a tendency ($0.05 < P \leq 0.10$), the comparisons were categorized as significant ($P \leq 0.05$) or non-significant ($P > 0.10$). For studies that utilized polynomial contrasts, if the polynomial *P*-value was significant or indicated a tendency, the same *P*-value was assigned to all comparisons in the polynomial contrast despite the numeric difference of the response to reflect the general effect of adding the additive on finding a significant difference. If the polynomial *P*-value was not significant, the determination of the *P*-value was based on the *P*-value of the pairwise comparison if available. If the pairwise comparison was unavailable, the nonsignificant polynomial *P*-value was used for all comparisons. For studies with factorial treatment structure, the combined means and main effect *P*-values were extracted if there was no significant interactive effect, regardless of the other factors. If there was a significant or a tendency of interactive effect of either variable, all possible comparisons were extracted separately for all variables of interest. However, if the other factor in the basal diets was the addition of ractopamine, the data was not extracted. For each response of the feed additive, the number of the extracted comparisons was counted, and the percentage difference was used to summarize the average positive, neutral, and negative effects of the feed additives at each significant level as a descriptive statistical analysis.

Materials & Methods: Objective 2a

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing site in southwest Minnesota. The barns were naturally ventilated and double-curtain-sided. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a bowl waterer for *ad libitum* access to feed and water.

Animals and diets

Two groups of pigs (1,833 total pigs; PIC 337 × 1050; initially 58.5 ± 1.62 lb) were used in a 112-d growth trial. Pigs were housed in mixed gender pens with 20 (group 1) and 27 (group 2) pigs per pen and 26 pens per treatment (13 replications per group) in a completely randomized design. There were three treatment diets: 1) control with no added L-Carnitine; 2) diets containing 50 ppm of L-Carnitine for the entire trial; and 3) control diets until d 84 and then a diet containing 50 ppm of L-Carnitine fed until marketing. In each group, 26 pens were assigned to a control diet (with no L-Carnitine added) and 13 pens to a diet containing 50 ppm of L-Carnitine. On d 84, 13 pens from the control treatment were randomly assigned to the diet with L-Carnitine. Experimental diets were corn-soybean meal-DDGS-based and fed in four phases. L-Carnitine was added to the diets via the vitamin and trace mineral premix, with all other premix ingredients being equal. All diets consisted of the same basal formulation and were fed in meal form. Phase 1 was fed from 60 to 100 lb, phase 2 from 100 to 160 lb, phase 3 from 160 to 225 lb, and phase 4 from 225 lb to market.

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. Pigs were weighed approximately every 14 d to determine ADG, ADFI, and F/G. On d 98, the 2 (group 1) and 3 (group 2) heaviest pigs in each pen were selected and marketed, but not included in the final pen carcass data. On the last day of the trial, final pen weights were obtained and the remaining pigs were tattooed with a pen identification number and transported to a U.S. Department of Agriculture-inspected packing plant (JBS Swift, Worthington, MN) for carcass data collection. Carcass measurements included HCW, loin depth, backfat, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight obtained at the farm, discounting culled pigs that did not meet the packing plant standards.

Statistical analysis

Data were analyzed using the GLIMMIX procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC) in a complete randomized design with pen serving as the experimental unit and initial BW serving as a covariate when it reduced the Bayesian Information Criteria. Random effect of group was included in the model for all response variables. Hot carcass weight served as a covariate for the analysis of backfat, loin depth, and lean percentage. Results from the experiment were considered significant at $P < 0.05$ and a marginally significant between
$P > 0.05$ and $P \leq 0.10$.

Materials & Methods: Objective 2b

General

Kansas State University Institutional Animal Care and Use Committee approved the protocol for this experiment. Two rooms at a commercial research grow-finish site located in southcentral Minnesota (Holden Farms, Northfield, MN) were used for this experiment. Barns had completely slatted, concrete flooring and contained pens (10 × 18 ft) equipped with a three-hole feeder (Thorp Equipment, Inc., Thorp, WI) and double-sided pan waterer. Pigs were provided *ad libitum* access to feed and water. A computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) provided daily feed additions.

Animals and diets
A total of 2,200 pigs (PIC 800 × Camborough; PIC, Hendersonville, TN; initially 53.4 ± 0.66 lb) were used to conduct a 117-d growth trial. Pens of pigs (25 pigs per pen) were randomly assigned to 1 of 4 dietary treatments in a randomized complete block design with 22 replicates per treatment. Dietary treatments were corn-soybean meal-based with the addition of none, 0.25, 0.50, or 0.75% Formi NDF (ADDCON Nordic AS, Porsgrunn, Norway). This product is a combination of 57% sodium formate and 38.5% formic acid. All diets were manufactured at Bixby Feed Mill, Inc. (Blooming Prairie, MN). Diets were fed in 6 phases from 53 to 75, 75 to 145, 145 to 195, 195 to 245, 245 to 265, and 265 to 310 lb body weight. Nutrients for all treatment diets were formulated to meet or exceed the NRC 2012 requirements for growing-finishing pigs in each appropriate weight ranges.

Pen of pigs were weighed every two weeks and feed disappearance was measured to determine ADG, ADFI, and F/G. Two weeks prior to the end of the experiment, 4 pigs per pen were weighed and marketed. The remaining pigs were weighed and marketed at the completion of the study. Pigs were transported to a U.S. Department of Agriculture-inspected packing plant. Hot carcass weight, loin depth, and backfat measurements were collected. Carcass yield was determined using the pen average HCW divided by the pen average final live weight. A proprietary equation from the packing plant was used to calculate the percentage lean.

Statistical analysis
Data were analyzed using the GLIMMIX procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC) in a randomized complete block design for a one-way ANOVA. Pen served as the experimental unit, treatment served the fixed effect, and initial body weight served as a blocking factor. Contrasts were used to test for the main effects of the different Formi NDF feeding levels (0, 0.25, 0.50, and 0.75%). Results were considered significant with $P \leq 0.05$ and marginally significant with $P \leq 0.10$. Contrasts were also used to analyze carcass characteristics including backfat, loin depth, and percent lean with HCW weight serving as a covariate.

Materials & Methods: Objective 3
General
The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This experiment was conducted at a commercial research facility located in southwest Minnesota (Pipestone Nutrition; Edgerton, MN). Pigs were housed in a temperature-controlled wean-to-finish facility. Each pen (22.4 × 8.3 ft) contained 1 nipple waterer and a 4-hole dry self-feeder to allow for *ad libitum* access to feed and water. Pigs were allowed approximately 6.9 ft^2/pig.

Animal treatment and structure
A total of 2,162 pigs (PIC 1050 × DNA 600; initially 69.2 ± 4.9 lb) were used in a 109-d finishing trial. There were 27 or 28 pigs per pen and 20 pens per treatment. On d 0,

pens were blocked by location in the barn and randomly allotted to 1 of 4 dietary treatments. A similar number of barrows and gilts were placed in each pen. Dietary treatments were arranged in a 2 × 2 factorial with main effects of soybean meal source and benzoic acid. Diets contained either conventional soybean meal (SBM) or extruded-expelled soybean meal (EESBM; Lester Feed and Grain, Lester IA) with or without the inclusion of VevoVitall (DSM Products; Parsippany, NJ), a source of benzoic acid added at 0.25%. Pens of pigs and feed disappearance were measured on d 0, 13, 28, 51, 62, 82, 90, 98, and 109 to determine ADG, ADFI, and F/G. Pigs were individually ear tagged with LeeO ear tags at the start of the trial. On d 88 and 96, eight of the heaviest pigs per pen were weighed individually and transported to a commercial packing plant (WholeStone Farms, Fremont, NE) for processing and determination of carcass characteristics. The remaining pigs were marketed at the conclusion of this trial on d 109 and transported to WholeStone Farms for carcass characteristic collection. A fat sample was taken from the belly from one barrow per pen per marketing event and included all three layers of fat. Analysis of iodine value was conducted using near-infrared spectroscopy (NIR) at WholeStone Farms.

Diet preparation
Experimental diets were fed in 6 different phases. Pigs were fed on a feed budget with phases 1, 2, 3, 4, and 5 provided at 42, 93, 108, 110, and 100 lb per pig, respectively. Phase 6 was provided for the remainder of the study. Digestible AA levels for EESBM were assumed at 2.39% for Lys, 1.52% for Thr, 0.53% for Trp, 1.77% for Ile, 1.85% for Val, 0.54% for Met, 0.54% for Cys, and 2.90% for Leu. The ME of conventional SBM was assumed at 1,309 kcal/lb and ME value for EESBM was assumed at 1,650 kcal/lb. All nutrients were formulated to meet or exceed NRC (2012) requirement estimates. Lysine HCl was formulated to remain very similar across all treatments within phase to allow the SBM source to be used to help balance the dietary SID Lys level. All diets were corn-soybean meal-based and were fed in meal form. Diets were manufactured at the Spronk Brothers Feed Mill (Edgerton, MN).

Chemical analysis
Diet samples for each treatment were collected at the end of each phase. Samples from each room for each treatment were then combined to create a composite sample and analyzed for proximate analysis (Midwest Laboratories; Omaha, NE). A separate composite sample was sent for amino acid analysis (Ajinomoto; Chicago, IL). Conventional SBM and EESBM were collected weekly from the feed mill and analyzed for proximate analysis and amino acid analysis (Midwest Laboratories; Omaha, NE).

Economic analysis
For economic analysis, gain per pig placed, total feed cost per pig, revenue, and income over feed cost were calculated using 4 different low and high revenue and feed cost scenarios. Feed cost per lb of gain was calculated by dividing feed cost per pig by the total weight gained using a low and high feed cost scenario. Revenue per pig placed was determined by total gain times the dressing percentage (0.75) and then multiplied by a carcass price of $0.55 for the low revenue scenario and $0.95 for the high scenario. Income over feed cost was calculated by using the low or high revenue per pig placed minus the low or high feed cost per pig placed. The following ingredient costs were used for the low cost scenario: corn = $3.36/bu ($120/ton); soybean meal = $280/ton; EESBM = $340/ton; DDGS = $160/ton; and benzoic acid = $1.15/lb. For the high cost scenario, the following ingredient costs were used: corn = $6.72/bu

($240/ton); soybean meal = $420/ton; EESBM = $500/ton; DDGS = $260/ton; and benzoic acid = $1.15/lb.

Statistical analysis
Data were analyzed using the GLIMMIX procedure of SAS OnDemand for Academics (SAS Institute, Inc., Cary, NC) in a randomized complete block design with pen as the experimental unit and location as the blocking factor. Treatments were considered a fixed effect and block as a random effect. The interaction and main effects of soybean meal source and benzoic acid inclusion were analyzed. The model for mortality and removal data specified a binomial distribution. Differences between treatments were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Materials & Methods: Objective 4
General
The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The facility was totally enclosed and environmentally regulated, containing 36 pens in each barn. Each pen was equipped with a two-hole dry single-sided feeder (Farmweld, Teutopolis, IL) and a 1-cup waterer. Pigs were stocked at a floor space of approximately 7.0 ft^2 per pig. Pens were equipped with adjustable gates to allow space allowances per pig to be maintained if a pig died or was removed from a pen during the experiment. Pens were located over a completely slatted concrete floor with a 4-ft pit underneath for manure storage. A robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) was used to deliver and record daily feed additions to each individual pen.

Animals and diets
A total of 695 pigs (600 × 241, DNA; initially 242.7 ± 1.36 lb) were used in a 14-d trial. Pigs were housed in mixed gender pens with 9 or 10 pigs per pen and 24 pens per treatment. Pens of pigs were weighed 5 d prior to the start of the trial and assigned to 1 of 3 treatments in a randomized complete block design with initial weight as a blocking factor. Treatments consisted of none, 6, or 12 h of feeder closure prior to loading pigs on the truck at both the first (2 weeks before final marketing) and final marketing to achieve approximately 12, 18, and 24 h of feed withdrawal prior to harvest at the processing plant. Pigs were loaded out of barns at 8:30 p.m. at each marketing event. Pigs were fed a corn-soybean meal-based diet that was formulated to meet or exceed nutrient requirements for pigs weighing 240 to 280 lb.

Pigs and feeders were weighed at the first and final marketing event at 8:30 a.m. and 8:30 p.m. to determine feed intake and individual BW within the marketing day, and to calculate ADG, ADFI, and F/G using gain and feed intake of the pens between the first and final marketing events. Feeders from treatments with 18 and 24 h of feed withdrawal prior to harvest were closed at 8:30 a.m. and 2:30 p.m., respectively, whereas feeders from the treatment with 12 h of feed withdrawal prior to harvest remained open. On the first marketing event, the 3 heaviest pigs in each pen were selected for marketing. After the first marketing, each pen was adjusted to maintain floor space per pig of approximately 7.0 ft^2. Pigs also were individually identified with an electronic tag and a tattoo for carcass data collection and transported to a USDA-inspected packing plant (Triumph Foods, St. Joseph, MO) for slaughter at 8:30 a.m. the following day. Carcass measurements included HCW, loin depth, backfat, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the individual live weight recorded in the morning and in the evening of each marketing event. Gross revenue was calculated using the HCW calculated using the body weight collected 24 h before slaughter as a covariate, multiplied by a hot carcass price of $0.90/lb.

Statistical analysis
Data were analyzed as a randomized complete block design for one-way ANOVA using the lmer function from the lme4 package in R (version 4.4.1 (2021-08-10), R Foundation for Statistical Computing, Vienna, Austria) with pen considered as the experimental unit, initial weight as blocking factor, and treatment as a fixed effect. The overall period was calculated by doing a weighted average of the first and final event values for each analysis. The BW collected 24 h before slaughter was used as covariate for analysis of HCW. Hot carcass weight was used as a covariate for backfat, loin depth, and percentage lean.

Results: Objective 1

Response to each feed additive is summarized for the different response criteria in Tables 1 and 2. Overall, the greatest proportion of the comparisons for each feed additive was positive; however, most of them were also not statistically significant. For most feed additives, there were enough comparisons to show the general effects of feed additives on ADG and G:F. For carcass characteristics, the overall effects were also positive; however, there were fewer comparisons, and effects were mostly small and inconsistent. Moreover, the sampling process for carcass characteristics often only selects a small portion of the animals used for the growth performance data, which accentuated the between-animal variations for the relatively small treatment effects. This resulted in a high proportion of the comparisons having no evidence of difference.

Feed additives Cr, carbohydrase, protease, phytase, and Zn had minor effects on growth performance compared to the results with other additives. Essential oil consistently improved ADG and G:F with a relatively larger magnitude (> 3%), but the number of comparisons was low, and most studies were not US-based; therefore, publication bias and locational effect may be concerning. On the other hand, acidifier, betaine, CLA, L-carnitine, and yeast had relatively substantial positive effects (2.5 to 3.5 %) on G:F. Moreover, despite limited data, benzoic acid and other acidifiers may be a potential additive for improving ADG and G:F, but further research is needed. The effects of Cu were most studied, with a 2.5% improvement in ADG, but the average effect on G:F was minor (1.8%). Moreover, DFM and multi-enzyme had relatively big and consistent improvements (approximately 3%) in ADG and G:F with a decent number of comparisons; however, there were relatively fewer US-based studies for DFM. Therefore, acidifiers, betaine, CLA, DFM, multi-enzyme, L-carnitine, and yeast products may be feed additives with the greatest opportunity for improving finishing pig G:F. However, the inclusion level and feeding strategy need further research for many of these additives. Lastly, most feed additives showed little and non-significant effects on carcass characteristics, except betaine, Cr, CLA, and L-carnitine. These feed additives may have the potential to improve carcass characteristics because of their mechanisms on lipid and energy metabolism.

Table. 1 Summary of the effects of feed additives on grow-finish pig ADG.

			Positive			Neutral	Negative		
Item	Comparisons, n	Difference, %[2]	Sig.	Tendency	NS.		NS.	Tendency	Sig.
Acidifier	68	1.7	18 (5.8)	0	31 (3.4)	0	15 (-3.4)	0	4 (-10.8)
Essential oil	20	5.8	10 (9.9)	0	6 (3.8)	1	3 (-1.7)	0	0
DFM	71	3.3	25 (6.3)	2 (3.9)	30 (3.6)	0	13 (-2.3)	0	1 (-5.8)
Yeast	36	1.6	9 (5.6)	0	16 (3.2)	0	11 (-4.1)	0	0
Copper	155	2.5	30 (6.2)	3 (4.1)	81 (3.8)	7	33 (-3.4)	0	1 (-0.1)
Zinc	30	0.6	1 (18.7)	1 (1.1)	12 (4.0)	4	11 (-3.2)	0	1 (-14.4)
Betaine	37	1.3	7 (10.6)	1 (4.3)	10 (2.4)	2	15 (-3.3)	0	2 (-2.8)
Chromium	139	1.1	14 (8.9)	4 (4.6)	51 (3.6)	10	48 (-2.2)	5 (-4.1)	7 (-7.2)
CLA	62	1.2	5 (7.2)	1 (3.6)	34 (3.7)	2	17 (-4.1)	0	3 (-7.8)
L-carnitine	24	2.1	2 (3.3)	4 (3.1)	13 (3.4)	1	3 (-2.6)	0	1 (-4.8)
Carbohydrase	87	1.3	15 (5.3)	5 (4.0)	35 (2.9)	4	24 (-3.3)	0	4 (-2.7)
Protease	23	0.6	3 (5.2)	4 (3.2)	9 (2.1)	0	5 (-3.7)	0	2 (-7.6)
Phytase	24	1.1	3 (6.8)	0	12 (2.6)	1	8 (-3.0)	0	0
Multi-enzyme	29	3.1	10 (7.9)	0	10 (2.9)	1	8 (-2.3)	0	0

[1]Significant (Sig.; $P < 0.05$), tendency ($0.05 \leq P < 0.10$), and non-significant (NS.; $P > 0.10$).

[2]Average of the % of difference of all the comparisons.

[3]Number outside of the parentheses represents the number of comparisons. Number inside the parentheses represents the average of the percentage of difference of these comparisons.

Figure 1. The distribution of the result of feed additives on ADG by significance level and direction. The comparison was significant (Sig.) if $P < 0.05$, had a tendency (T.) if $0.05 \leq P < 0.10$, and was non-significant (NS.) if $P > 0.10$.

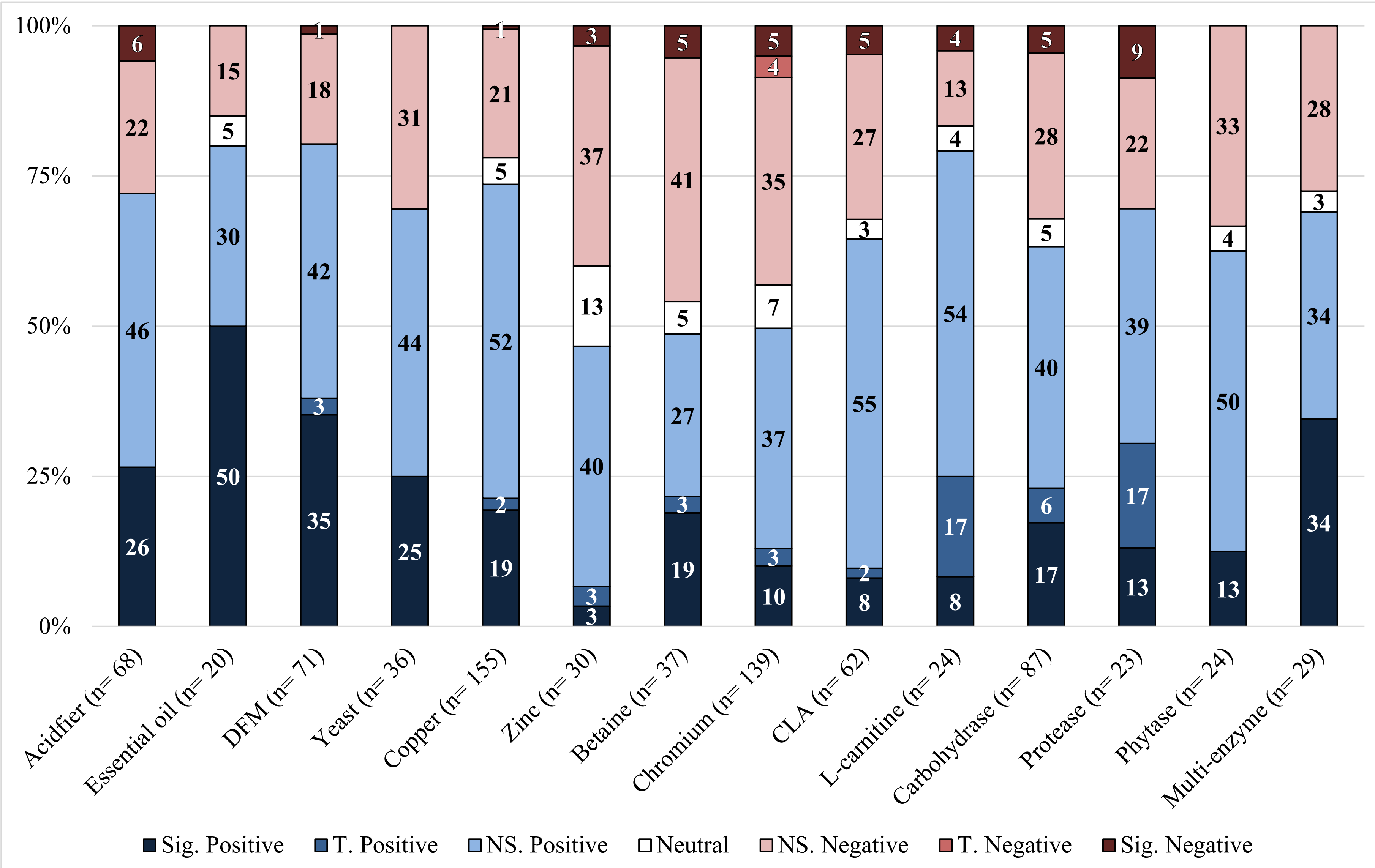


Table. 2 Summary of the effects of feed additives on grow-finish pig G:F.

Item	Comparisons, n	Difference, %[2]	Positive			Neutral	Negative		
			Sig.	Tendency	NS.		NS.	Tendency	Sig.
Acidifier	65	3.1	13 (6.4)	0	40 (3.8)	2	9 (-3.1)	0	1 (-9.7)
Essential oil	17	5.8	7 (10.9)	1 (4.5)	6 (3.5)	1	2 (-1.5)	0	0
DFM	66	3.3	18 (6.1)	3 (3.0)	32 (3.9)	2	11 (-2.2)	0	0
Yeast	33	2.7	10 (7.8)	0	12 (3.9)	1	10 (-3.6)	0	0
Copper	149	1.8	30 (5.1)	3 (1.0)	71 (3.1)	6	37 (-2.7)	0	2 (-3.7)
Zinc	30	1.2	0	4 (1.2)	14 (4.2)	1	11 (-2.6)	0	0
Betaine	35	2.7	5 (13.2)	0	18 (2.7)	2	9 (-2.3)	0	1 (-0.4)
Chromium	138	1.0	14 (5.2)	0	60 (3.1)	16	41 (-2.1)	0	7 (-4.3)
CLA	57	3.5	13 (4.5)	6 (8.8)	24 (4.6)	4	9 (-2.3)	0	1 (-2.8)
L-carnitine	24	2.5	1 (2.9)	3 (3.7)	13 (4.4)	2	5 (-2.0)	0	0
Carbohydrase	84	1.7	8 (8.5)	2 (5.9)	46 (2.9)	9	19 (-3.8)	0	0
Protease	22	1.8	7 (4.9)	1 (7.6)	5 (2.2)	2	7 (-2.0)	0	0
Phytase	24	1.1	2 (5.7)	1 (2.9)	13 (2.3)	1	7 (-2.5)	0	0
Multi-enzyme	29	3.3	10 (9.0)	0	12 (1.8)	2	5 (-3.3)	0	0

[1]Significant (Sig.; $P < 0.05$), tendency ($0.05 \leq P < 0.10$), and non-significant (NS.; $P > 0.10$).

[2]Average of the % of difference of all the comparisons.

[3]Number outside of the parentheses represents the number of comparisons. Number inside the parentheses represents the average of the percentage of difference of these comparisons.

Figure 2. The distribution of the result of feed additives on G:F by significance level and direction. The comparison was significant (Sig.) if $P < 0.05$, had a tendency (T.) if $0.05 \le P < 0.10$, and was non-significant (NS.) if $P > 0.10$.

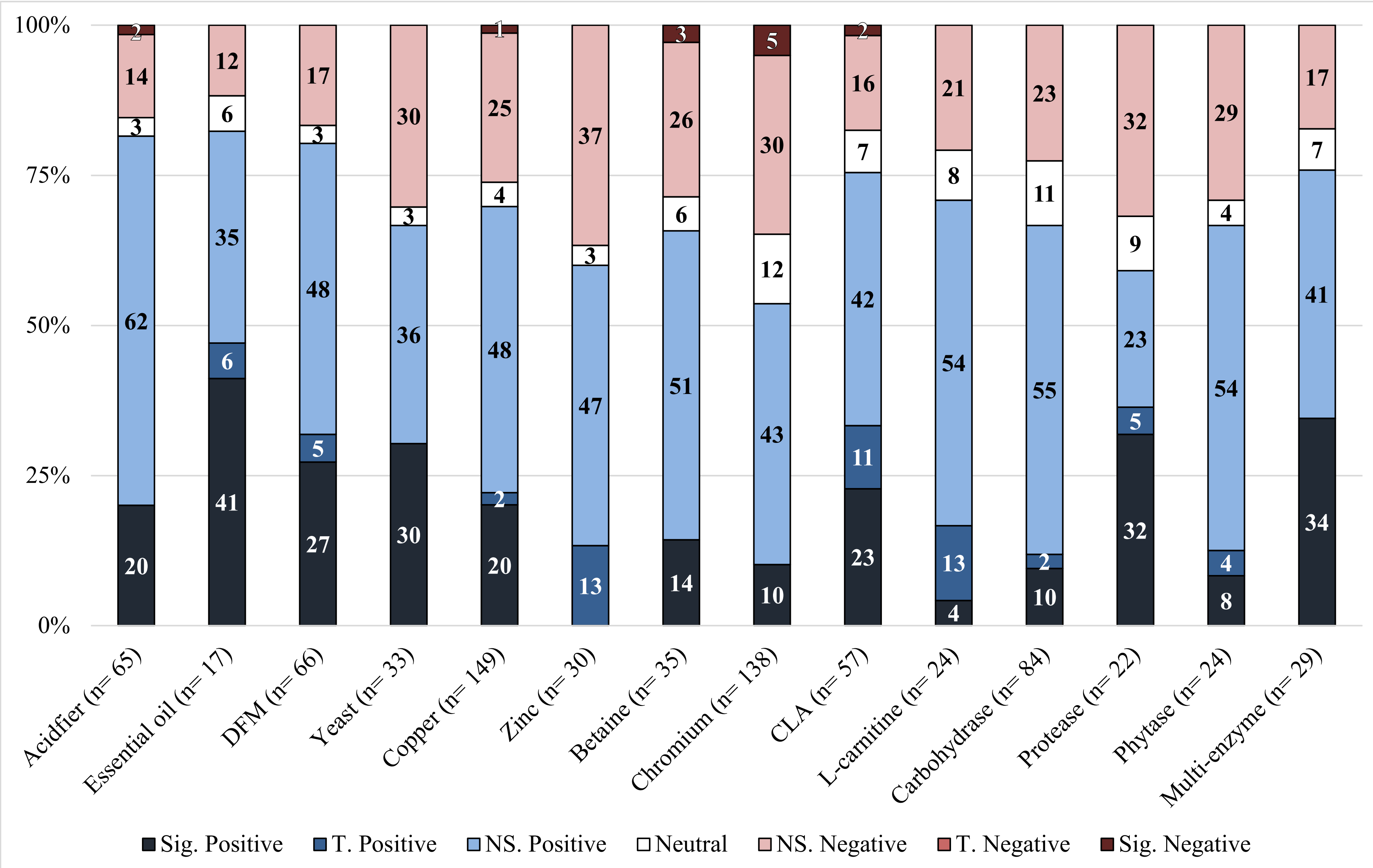


Table. 3 Summary of the effects of feed additives on grow-finish pig BF.

Item	Comparisons, n	Difference, %[2]	Positive			Neutral	Negative		
			Sig.	Tendency	NS.		NS.	Tendency	Sig.
Acidifier	24	-0.6	0	0	14 (2.6)	2	5 (-3.2)	0	3 (-12)
Essential oil	14	-2.7	0	0	5 (3.7)	0	6 (-5.5)	0	3 (-2.7)
DFM	21	-1.5	1 (16.8)	0	6 (7.1)	0	9 (-6.3)	3 (-2.9)	2 (-13.1)
Yeast	21	-3.1	0	0	12 (4.1)	1	8 (-14.4)	0	0
Copper	73	-1.4	0	0	24 (3.5)	9	36 (-4.1)	1 (-5.4)	3 (-10.3)
Zinc	19	-0.6	1 (13.1)	0	5 (1.3)	2	11 (-2.9)	0	0
Betaine	32	-1.7	0	0	13 (2)	0	16 (-2.9)	0	3 (-10.7)
Chromium	133	-3.9	2 (8)	5 (6.3)	42 (4.2)	2	53 (-6.4)	7 (-12.4)	22 (-14.4)
CLA	59	-7.0	0	0	14 (4)	2	16 (-6.1)	5 (-6.5)	22 (-15.4)
L-carnitine	22	-3.4	3 (4)	2 (1.4)	1 (1.9)	1	6 (-5.7)	7 (-4.8)	2 (-12.5)
Carbohydrase	57	-0.4	2 (4.1)	1 (4.8)	18 (4)	7	29 (-3.7)	0	0
Protease	13	-0.1	0	3 (3.7)	3 (4.5)	1	6 (-4.4)	0	0
Phytase	14	-0.2	1 (8.3)	0	6 (1.7)	2	5 (-4.2)	0	0
Multi-enzyme	12	2.8	0	0	6 (10.4)	0	5 (-3.8)	0	1 (-10.2)

[1]Significant (Sig.; $P < 0.05$), tendency ($0.05 \leq P < 0.10$), and non-significant (NS.; $P > 0.10$).

[2]Average of the % of difference of all the comparisons.

[3]Number outside of the parentheses represents the number of comparisons. Number inside the parentheses represents the average of the percentage of difference of these comparisons.

Figure 3. The distribution of the result of feed additives on BF by significance level and direction. The comparison was significant (Sig.) if $P < 0.05$, had a tendency (T.) if $0.05 \leq P < 0.10$, and was non-significant (NS.) if $P > 0.10$.

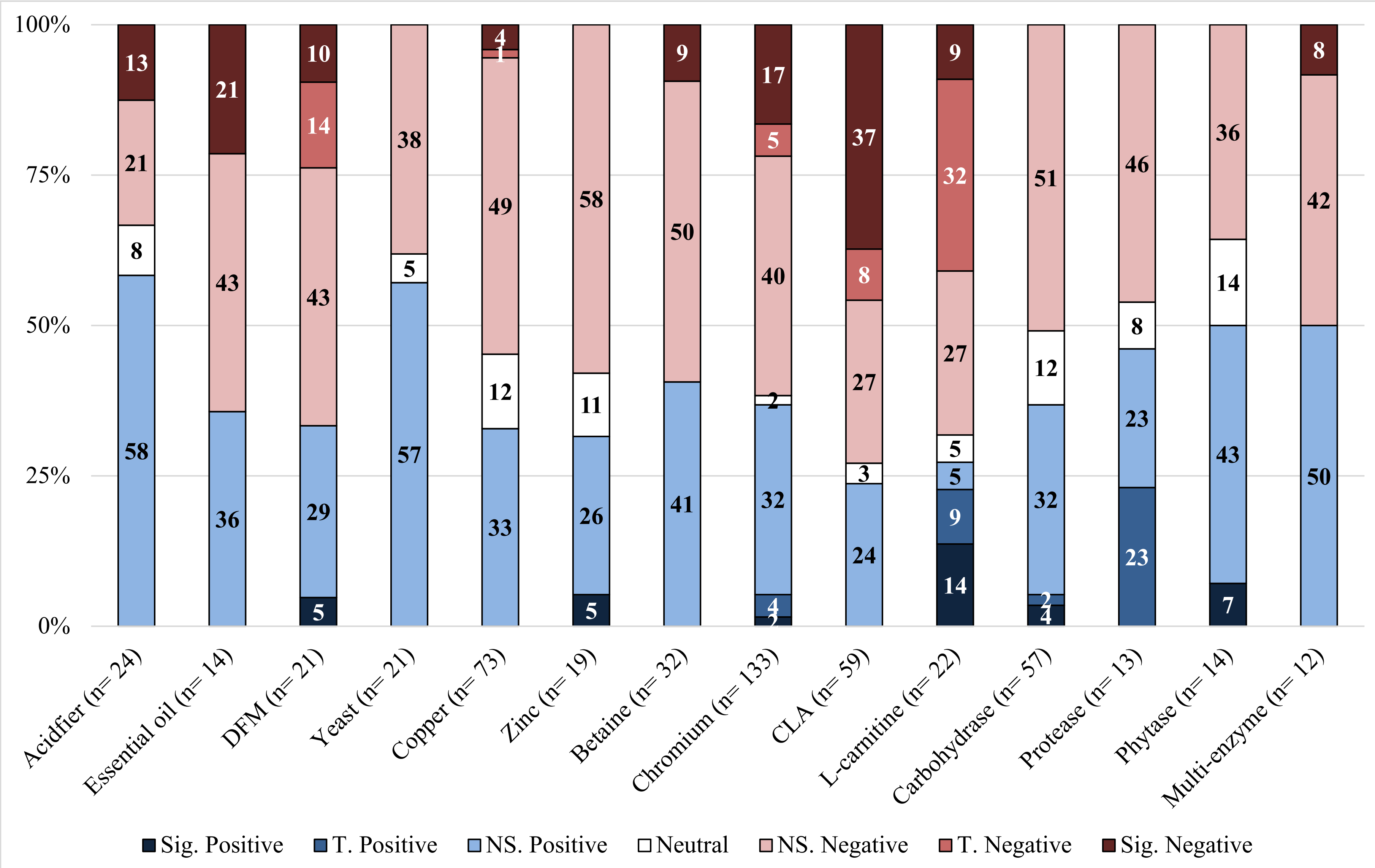


Table. 4 Summary of the effects of feed additives on grow-finish pig % lean.

			Positive			Neutral	Negative		
Item	Comparisons, n	Difference, %[2]	Sig.	Tendency	NS.		NS.	Tendency	Sig.
Acidifier	24	-0.5	0	0	9 (0.9)	0	15 (-1.4)	0	0
Essential oil	9	0.9	3 (2.5)	0	3 (1.2)	1	2 (-1.5)	0	0
DFM	13	1.0	0	1 (1.8)	9 (1.8)	0	3 (-1.8)	0	0
Yeast	8	1.0	0	3 (0.8)	2 (4.9)	0	2 (-1.3)	1 (-1.2)	0
Copper	25	1.6	2 (1.1)	0	16 (2.8)	0	7 (-1.1)	0	0
Zinc	14	0.9	0	0	12 (1.1)	1	1 (-0.4)	0	0
Betaine	25	2.0	1 (5.2)	0	15 (3.6)	1	8 (-1.2)	0	0
Chromium	105	1.6	20 (6.6)	1 (5)	43 (1.9)	3	36 (-1.2)	0	2 (-4.1)
CLA	37	2.6	14 (4.9)	0	16 (1.9)	0	7 (-0.6)	0	0
L-carnitine	20	1.1	4 (3.8)	2 (1.5)	7 (1.5)	1	3 (-0.7)	0	3 (-1.3)
Carbohydrase	55	0.3	1 (5.6)	0	28 (1.1)	4	20 (-0.8)	0	2 (-0.7)
Protease	13	0.0	0	0	6 (1.1)	1	6 (-1.1)	0	0
Phytase	9	0.0	0	0	4 (0.6)	0	5 (-0.5)	0	0
Multi-enzyme	9	0.7	1 (4.4)	0	6 (0.6)	0	2 (-0.9)	0	0

[1]Significant (Sig.; $P < 0.05$), tendency ($0.05 \leq P < 0.10$), and non-significant (NS.; $P > 0.10$).

[2]Average of the % of difference of all the comparisons.

[3]Number outside of the parentheses represents the number of comparisons. Number inside the parentheses represents the average of the percentage of difference of these comparisons.

Figure 4. The distribution of the result of feed additives on % lean by significance level and direction. The comparison was significant (Sig.) if $P < 0.05$, had a tendency (T.) if $0.05 \leq P < 0.10$, and was non-significant (NS.) if $P > 0.10$.

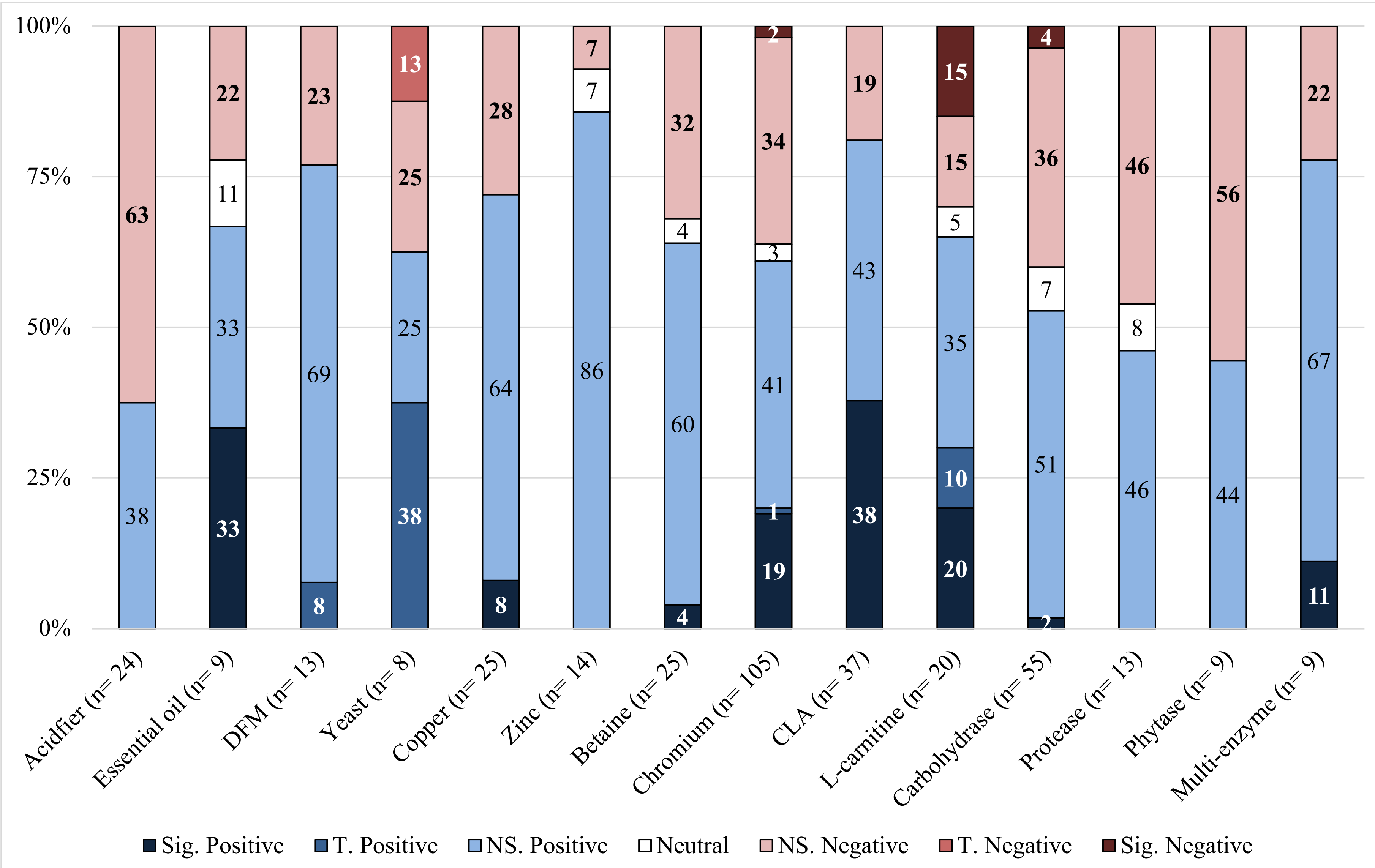


Table. 5 Summary of the effects of feed additives on grow-finish pig LMA/LD.

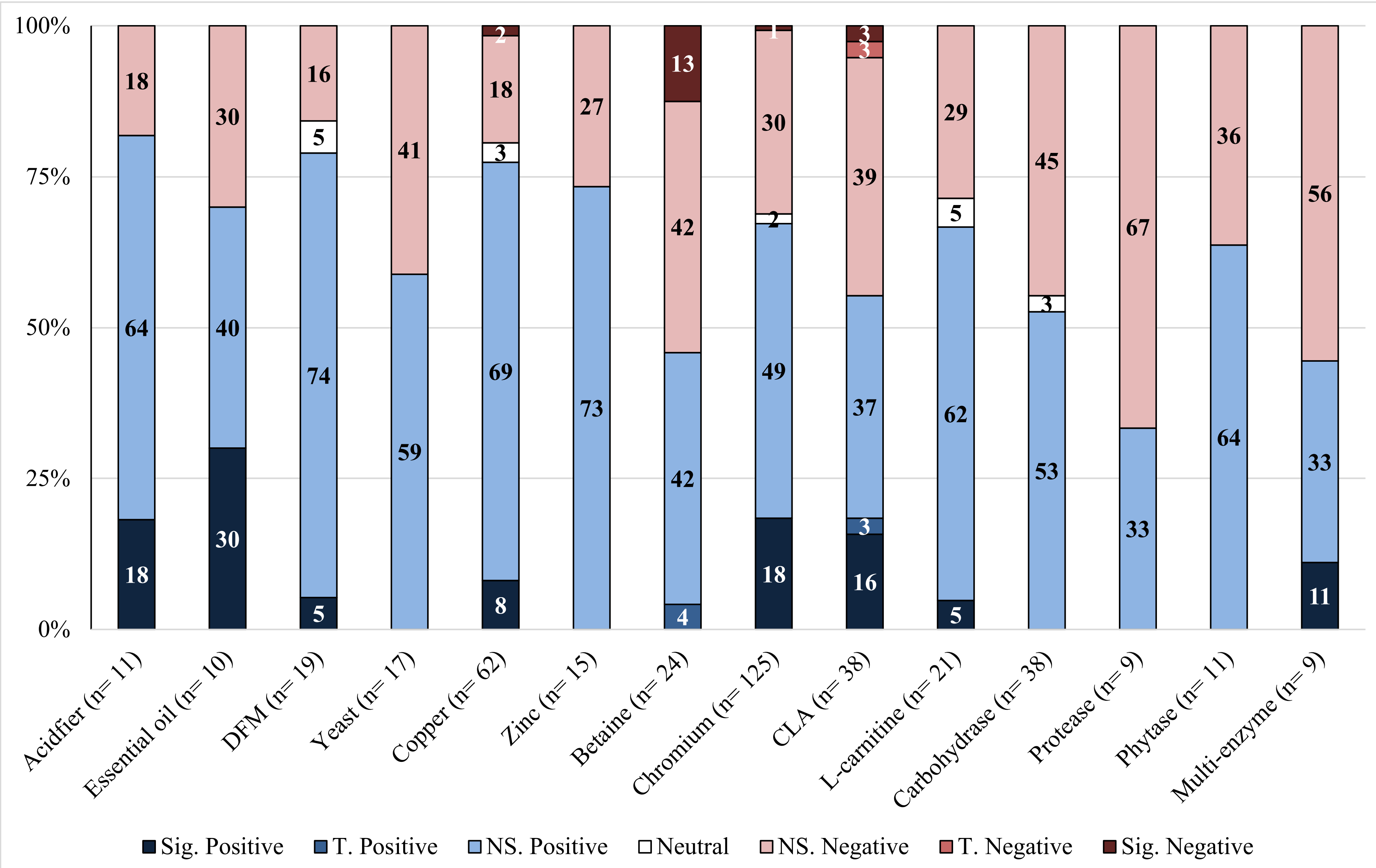
			Positive			Neutral	Negative		
Item	Comparisons, n	Difference, %[2]	Sig.	Tendency	NS.		NS.	Tendency	Sig.
Acidifier	11	1.6	2 (6.3)	0	7 (2.6)	0	2 (-6.9)	0	0
Essential oil	10	1.9	3 (7.1)	0	4 (1)	0	3 (-2.3)	0	0
DFM	19	1.5	1 (10.9)	0	14 (2)	1	3 (-3.4)	0	0
Yeast	17	1.4	0	0	10 (3.6)	0	7 (-1.9)	0	0
Copper	62	2.3	5 (4.4)	0	43 (3.4)	2	11 (-1.4)	0	1 (-7.5)
Zinc	15	0.2	0	0	11 (0.9)	0	4 (-1.5)	0	0
Betaine	24	-0.2	0	1 (6.3)	10 (1.9)	0	10 (-2.2)	0	3 (-2.3)
Chromium	125	3.1	23 (13.9)	0	61 (3.2)	2	38 (-3)	0	1 (-11.6)
CLA	38	0.9	6 (7.6)	1 (3.7)	14 (3)	0	15 (-3)	1 (-4.8)	1 (-5.9)
L-carnitine	21	2.4	1 (6.3)	0	13 (4.4)	1	6 (-2.3)	0	0
Carbohydrase	38	1.1	0	0	20 (3.3)	1	17 (-1.5)	0	0
Protease	9	-2	0	0	3 (2.4)	0	6 (-4.1)	0	0
Phytase	11	-1.4	0	0	7 (1.7)	0	4 (-6.9)	0	0
Multi-enzyme	9	0.3	1 (11.3)	0	3 (1.8)	0	5 (-2.8)	0	0

[1]Significant (Sig.; $P < 0.05$), tendency ($0.05 \leq P < 0.10$), and non-significant (NS.; $P > 0.10$).

[2]Average of the % of difference of all the comparisons.

[3]Number outside of the parentheses represents the number of comparisons. Number inside the parentheses represents the average of the percentage of difference of these comparisons.

Figure 5. The distribution of the result of feed additives on LMA/LD by significance level and direction. The comparison was significant (Sig.) if $P < 0.05$, had a tendency (T.) if $0.05 \leq P < 0.10$, and was non-significant (NS.) if $P > 0.10$.



Results: Objective 2a

From d 0 to 28, there were improvements for ADG (*P* = 0.001) and ADFI (*P* = 0.002) observed for pigs fed L-Carnitine compared to the control resulting in heavier (*P* = 0.001) BW on d 28 (Table 2). No difference was observed for F/G. From d 29 to 56 and d 57 to 84, there was no evidence of differences (*P* > 0.131) for ADG, ADFI, and F/G among treatments.

On d 84, pigs fed L-Carnitine tended (*P* = 0.063) to be heavier than pigs fed control diets. From d 0 to 84, the L-Carnitine treatment had a tendency (*P* = 0.052) for greater ADFI; however, no differences (*P* > 0.144) were observed for ADG, F/G, removals, mortality, and total removal and mortalities.

From d 85 to market and overall (d 0 to 112), pigs on the control, L-Carnitine, and late L-Carnitine treatments had similar (*P* > 0.221) ADG, ADFI, F/G, removals, mortality, and total removals and mortality. Final BW was not affected (*P* = 0.180) by dietary treatment. When evaluating carcass characteristics, no differences (*P* > 0.540) were observed for HCW, carcass yield, backfat, percentage lean, and loin depth between treatments.

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

Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredients, %				
Corn	54.71	61.05	65.95	68.45
Soybean meal, 46% CP	17.34	11.20	6.68	4.22
DDGS	25.00	25.00	25.00	25.00
Calcium carbonate	1.45	1.40	1.30	1.25
Monocalcium P, 21% P	0.30	0.20	----	----
Salt	0.40	0.40	0.40	0.40
L-Lys-HCl	0.48	0.45	0.43	0.43
DL-Met	0.02	----	----	----
L-Trp	0.03	0.03	0.03	0.04
Thr[2]	0.11	0.10	0.08	0.08
Tribasic copper chloride	0.03	0.03	0.03	0.03
Phytase[3]	0.05	0.05	0.03	0.02
Vitamin-trace mineral premix	0.15	0.15	0.15	0.15
L-Carnitine[4]	+/-	+/-	+/-	+/-
Calculated analysis				
SID AA, %				
Lys	1.08	0.91	0.78	0.72
Ile:Lys	60	60	60	60
Leu:Lys	155	168	183	190
Met:Lys	29	30	33	34
Met and Cys:Lys	56	59	64	66
Thr:Lys	62	59	64	65
Trp:Lys	18.4	18.1	18.0	18.3
Val:Lys	71	73	76	77
SID Lys:NE, g/Mcal	4.53	3.75	3.17	2.91
NE, kcal/lb	1,082	1,100	1,116	1,123
Ca, %	0.67	0.61	0.53	0.50
STTD P, %	0.43	0.39	0.33	0.31
Chemical analysis, %				
CP, %	20.4	17.9	16.1	15.2
NDF, %	13.1	13.2	13.3	13.3

[1]Phases 1, 2, 3, and 4 were fed from 60 to 100, 100 to 160, 160 to 225, and 225 lb to market, respectively.
[2]Thr Pro, CJ America Bio, Fort Dodge, IA.
[3]Optiphos Plus 2500 G (Huvepharma Inc. Peachtree City, GA) provided 567.3 units of phytase FTY/lb of diet with an assumed release of 0.13% STTD P.
[4]50 ppm of L-Carnitine were added to diets via the vitamin and trace mineral premix.

Table 2. Growth performance and carcass characteristics of finishing pigs fed a diet with or without L-Carnitine, or with L-Carnitine the last 28 d prior to marketing[1,2]

	Treatment				
Item[3]	No L-Carnitine	L-Carnitine	Late L-Carnitine	SEM	*P*-value
BW, lb					
d 0	58.5	58.5	-	1.62	0.985
d 28	102.0	104.2	-	0.98	0.001
d 56	162.7	164.6	-	1.20	0.148
d 84	225.1	228.1	225.1	1.31	0.063
d 112	281.6	284.7	282.4	1.29	0.180
d 0 to 28					
ADG, lb	1.60	1.68	-	0.072	0.001
ADFI, lb	3.55	3.67	-	0.114	0.002
F/G	2.21	2.19	-	0.036	0.459
d 29 to 56					
ADG, lb	2.09	2.08	-	0.042	0.738
ADFI, lb	5.32	5.39	-	0.058	0.294
F/G	2.55	2.59	-	0.042	0.131
d 57 to 84					
ADG, lb	2.20	2.24	-	0.022	0.171
ADFI, lb	6.70	6.78	-	0.120	0.248
F/G	3.04	3.03	-	0.043	0.568
d 0 to 84					
ADG, lb	1.96	2.00	-	0.044	0.159
ADFI, lb	5.18	5.28	-	0.064	0.052
F/G	2.63	2.64	-	0.029	0.571
Removals, %	5.3	3.7	-	2.03	0.144
Mortality, %	1.8	2.3	-	0.60	0.481
Rem + Mort., %[4]	7.7	6.6	-	1.94	0.404
d 85 to Market					
ADG, lb	2.12	2.14	2.18	0.022	0.355
ADFI, lb	5.62	5.74	5.68	0.121	0.506
F/G	2.65	2.71	2.62	0.043	0.551
Overall (d 0 to 112)					
ADG, lb	1.97	2.00	1.98	0.017	0.300
ADFI, lb	5.66	5.73	5.62	0.109	0.236
F/G	2.87	2.86	2.84	0.038	0.221
Removals, %	5.7	4.2	5.8	2.40	0.371
Mortality, %	1.8	2.3	1.8	0.60	0.779
Rem. + Mort., %[4]	7.6	6.6	7.8	2.11	0.700
Carcass characteristics					
HCW, lb	207.5	209.7	207.8	2.81	0.705
Yield, %	72.9	72.8	72.8	0.10	0.989
Backfat, in.	0.65	0.65	0.64	0.016	0.774
Lean, %	56.4	56.3	56.6	0.29	0.755
Loin depth, in.	2.50	2.48	2.48	0.021	0.540

[1]A total of 1,833 pigs across two groups were used in a 112-d trial. Each pen contained 20 (group 1) and 27 pigs (group 2) and each treatment had 26 replicate pens.
[2]Treatment diets consisted of a control without L-Carnitine, 50 ppm of L-Carnitine fed for

the entire experiment, or 50 ppm of L-Carnitine fed during the last 28 d prior to marketing.
[3]Until d 84, comparisons were made between 52 pens on the control diet and 26 pens fed L-Carnitine.
[4]Represented by the sum of removals and mortalities.
[5]Carcass weight at processing plant divided by the final BW at the farm.

Results: Objective 2B

For period 1 (d 0 to 32), increasing sodium diformate tended to decrease (quadratic, $P = 0.081$) ADFI up to the 0.50% inclusion level. Furthermore, increasing sodium diformate had a quadratic ($P < 0.001$) effect on feed efficiency with the lowest F/G at the 0.25% inclusion level. There was no evidence of differences ($P > 0.05$) in ADG. For period 2 (d 32 to 60), there was no evidence for differences ($P > 0.05$) in ADG or ADFI; however, there was a tendency for a quadratic effect ($P = 0.092$) on feed efficiency with the 0.25 and 0.50% inclusion of sodium diformate having the lowest F/G. For period 3 (d 60 to 93), increasing sodium diformate increased (linear, $P < 0.01$) ADG and ADFI. However, there was no evidence for differences ($P > 0.05$) in feed efficiency. For period 4 (d 93 to 117), increasing sodium diformate in the diets increased (linear, $P < 0.05$) ADG, ADFI, and improved (linear, $P < 0.05$) feed efficiency.

For the overall period (d 0 to 117), pigs fed increasing sodium diformate had increased (linear, $P < 0.01$) ADG and a tendency for increased (linear, $P = 0.075$) ADFI; however, there was no evidence for differences ($P > 0.05$) in feed efficiency. Increasing sodium diformate increased (linear, $P = 0.005$) final BW on d 117.

For carcass characteristics, no evidence for differences ($P > 0.10$) were observed for any criteria including HCW, carcass yield, backfat, loin depth, or lean percentage due to increasing sodium diformate.

For economics, increasing sodium diformate in the diets increased (linear, $P < 0.001$) feed cost and feed cost per lb of gain in both low and high price ingredient scenarios. However, there was a tendency for a quadratic effect ($P = 0.059$) of revenue with pigs fed 0.25% sodium diformate generating the greatest revenue in both the low and high price ingredient scenarios. Due to the increased feed cost and quadratic response in revenue, pigs fed increasing Formi NDF had a quadratic ($P < 0.05$) response in IOFC with pigs fed no sodium diformate having the greatest IOFC.

Table 1. Composition of experimental diets (as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Ingredients, %						
Corn	42.96	52.96	60.73	64.54	69.38	82.73
Soybean meal (46.5% CP)	24.50	14.50	6.75	3.00	3.25	15.50
DDGS	30.00	30.00	30.00	30.00	25.00	0.00
Monocalcium P (21% P)	0.05	0.00	0.00	0.00	0.00	0.05
Limestone, ground	1.20	1.10	1.10	1.10	1.10	0.80
Salt	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys-HCl	0.36	0.49	0.51	0.49	0.45	0.19
Thr[2]	0.06	0.12	0.12	0.11	0.11	0.07
L-Trp	0.00	0.03	0.05	0.05	0.04	0.00
Vitamin premix	0.20	0.15	0.13	0.13	0.10	0.10
Trace mineral premix	0.15	0.13	0.10	0.10	0.08	0.08
Copper sulfate	0.03	0.03	0.03	0.00	0.00	0.00
Sodium diformate[3]	+/-	+/-	+/-	+/-	+/-	+/-
TOTAL	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	1.15	1.02	0.86	0.75	0.72	0.72
Ile:Lys	68	61	58	58	58	66
Leu:Lys	167	166	177	191	189	163
Met:Lys	30	29	31	33	33	30
Met and Cys:Lys	57	56	59	63	63	60
Thr:Lys	63	63	63	64	65	65
Trp:Lys	18	18	18	18	18	18
Val:Lys	78	73	72	75	74	76
His:Lys	46	43	43	44	44	47
Total Lys, %	1.34	1.18	0.99	0.88	0.83	0.79
NE, kcal/lb	1,118	1,129	1,136	1,140	1,149	1,181
SID Lys:NE, g/Mcal	4.67	4.11	3.42	3.00	2.83	2.76
CP, %	23.2	19.5	16.4	15.0	14.0	13.2
Ca, %	0.64	0.58	0.53	0.51	0.49	0.43
STTD P, %	0.41	0.38	0.35	0.34	0.31	0.26

[1]Phases were fed from approximately 53 to 75, 75 to 145, 145 to 195, 195 to 245, 245 to 265, and 265 to 310 lb body weight, respectively.
[2]Thr Pro; CJ America-Bio, Downers Grove, IL.
[3]Formi NDF (ADDCON Nordic AS, Porsgrunn, Norway) at 0.25, 0.50, and 0.75% of the diet was included at the expense of corn.

Table 2. Effect of increasing sodium diformate on grow-finish pigs growth performance and carcass characteristics[1]

Item	Sodium diformate, %[2]				SEM	*P* =	
	0	0.25	0.50	0.75		Linear	Quadratic
BW, lb							
d 0	53.4	53.4	53.5	53.4	0.66	0.808	0.538
d 32	117.7	117.9	117.4	117.4	0.88	0.445	0.834
d 60	180.3	181.3	180.7	180.5	1.03	0.954	0.359
d 93	256.3	258.1	257.9	258.2	1.05	0.118	0.338
d 117	306.0	308.2	309.1	309.5	1.54	0.005	0.307
Period 1 (d 0 to 32)							
ADG, lb	2.00	2.01	1.99	1.99	0.012	0.287	0.641
ADFI, lb	3.80	3.75	3.74	3.78	0.031	0.424	0.081
F/G	1.89	1.86	1.88	1.89	0.009	0.688	< 0.001
Period 2 (d 32 to 60)							
ADG, lb	2.23	2.26	2.26	2.24	0.017	0.646	0.166
ADFI, lb	5.42	5.46	5.44	5.44	0.039	0.810	0.580
F/G	2.43	2.41	2.41	2.43	0.011	0.648	0.092
Period 3 (d 60 to 93)							
ADG, lb	2.30	2.31	2.34	2.35	0.014	0.004	0.970
ADFI, lb	6.62	6.67	6.71	6.74	0.035	0.008	0.817
F/G	2.88	2.88	2.87	2.87	0.017	0.475	0.833
Period 4 (d 93 to 117)							
ADG, lb	2.36	2.41	2.43	2.46	0.034	0.003	0.708
ADFI, lb	7.90	8.00	8.00	8.07	0.048	0.017	0.798
F/G	3.36	3.33	3.30	3.28	0.039	0.033	0.822
Overall (d 0 to 117)							
ADG, lb	2.21	2.23	2.24	2.24	0.009	0.004	0.236
ADFI, lb	5.73	5.76	5.77	5.79	0.030	0.075	0.905
F/G	2.60	2.58	2.58	2.59	0.013	0.321	0.189
Carcass characteristics							
HCW, lb	224.2	225.8	227.3	225.7	1.33	0.168	0.107
Carcass yield, %	73.4	73.3	73.4	72.9	0.22	0.117	0.334
Lean, %[3]	57.3	57.3	57.3	57.2	0.08	0.719	0.383
Backfat, in[3]	0.52	0.51	0.51	0.51	0.006	0.207	0.380
Loin depth, in[3]	2.87	2.88	2.86	2.85	0.018	0.220	0.545
Removals, %	1.82	0.91	0.91	1.46	0.570	0.666	0.144
Mortality, %	1.09	0.91	1.09	1.46	0.511	0.545	0.562
Mortality and removals, %	2.91	1.82	2.00	2.91	0.717	0.934	0.133

Economics, $/pig placed							
Low ingredients prices[4]							
Feed cost	46.99	50.09	52.37	54.92	0.446	< 0.001	0.401
Feed cost/lb gain[5]	0.192	0.201	0.211	0.221	0.0010	< 0.001	0.175
Revenue[6]	107.87	109.64	109.47	108.58	0.738	0.526	0.059
IOFC[7]	60.88	59.52	57.10	53.66	0.465	< 0.001	0.025
High ingredients prices[8]							
Feed cost	80.21	83.67	85.75	88.26	0.737	< 0.001	0.380
Feed cost/lb gain[5]	0.328	0.336	0.345	0.356	0.0017	< 0.001	0.172
Revenue[6]	158.21	160.81	160.56	159.25	1.082	0.526	0.059
IOFC[7]	78.00	77.11	74.81	71.00	0.662	< 0.001	0.024

[1]A total of 2,200 pigs (initial BW of 53.4 lb) were used in a 117-d growth trial with 25 pigs per pen and 22 replicates per treatment.
[2] Formi NDF, ADDCON Nordic AS, Porsgrunn, Norway.
[3]Adjusted using HCW as covariate.
[4] Market price for the revenue calculation: Corn = $3.00/bushel ($107.14/ton); soybean meal = $300/ton; DDGS = $140/ton; L-Lys HCl = $0.65/lb; L-Trp = $3.00/lb; Thr Pro = $0.80/lb; FORMI NDF= $1.61/lb.
[5] Feed cost/lb gain = total feed cost per pig divided by total gain per pig.
[6] Revenue = (total gain × carcass yield) × carcass price. Revenue is based on a $0.60/lb or $0.88/lb carcass price for low- or high-priced scenarios, respectively.
[7] Income over feed cost = revenue – feed cost.
[8] Market price for the revenue calculation: Corn = $6.00/bushel ($214.29/ton); soybean meal = $400/ton; DDGS = $240/ton; L-Lys HCl = $0.80/lb; L-Trp = $5.00/lb; Thr Pro = $0.80/lb; FORMI NDF = $1.61/lb.

Results: Objective 3

For the proximate analysis, conventional SBM had higher CP and lower fat (acid hydrolysis) compared to EESBM. For the amino acid analyses, conventional SBM had collectively higher amino acid values compared to EESBM, with the exception of Cys and Pro (Table 1). In the complete diet analysis, diets had similar CP levels within phase (Table 2). As expected, fat levels were higher in diets containing EESBM compared to diets containing conventional SBM.

There were no interactions between soybean meal source and benzoic acid for any growth response criteria. Thus, only main effects will be discussed. From d 0 to 51, pigs fed EESBM had greater ($P = 0.01$) ADFI and improved ($P < 0.001$) F/G compared to pigs fed conventional SBM (Table 3). There was no effect of soybean meal source on ADG. Pigs fed diets without benzoic acid had greater ($P \leq 0.005$) ADG and ADFI compared to pigs fed diets containing benzoic acid. Pigs that were fed diets containing benzoic acid had improved ($P < 0.001$) F/G compared to pigs fed diets without benzoic acid.

From d 51 to 109, pigs fed conventional SBM had greater ($P = 0.06$) ADFI compared to pigs that were fed EESBM. Pigs fed EESBM had improved ($P < 0.001$) F/G compared to pigs fed conventional SBM. There was a tendency for an increase ($P = 0.06$) in ADG in pigs fed diets containing benzoic acid compared to pigs fed diets without benzoic acid. There were no main effects for benzoic acid on ADFI or F/G during this period.

Overall (d 0 to 109), pigs fed conventional SBM had greater ($P = 0.01$) ADFI compared to pigs fed EESBM without influencing ADG. Therefore, pigs fed EESBM had improved ($P < 0.001$) F/G compared to pigs fed conventional SBM. Also, pigs fed diets without benzoic acid had greater ($P = 0.02$) ADFI compared to pigs fed diets that contained benzoic acid without influencing ADG. As a result, pigs fed benzoic acid had improved ($P = 0.01$) F/G compared to pigs fed diets without benzoic acid.

There were no main effects for soybean meal source or benzoic acid on removals, mortality, or total removals and mortality for the duration of the study (Table 3).

When evaluating caloric efficiency, pigs fed diets containing benzoic acid had improved ($P < 0.001$) caloric efficiency compared to pigs fed diets without benzoic acid with no differences between soybean meal sources. This suggests that our initial estimate of ME for the EESBM was accurate.

For carcass characteristics, pigs fed EESBM had increased ($P < 0.001$) carcass fat iodine value. Benzoic acid did not influence carcass fat iodine value.

For economics, there was a main effect of soybean meal source where pigs fed EESBM had a higher ($P \leq 0.002$) feed cost per pig placed in the low and high feed cost scenarios. There were no differences in revenue per pig placed in the low or high revenue scenarios regardless of soybean meal source or the inclusion of benzoic acid. Pigs fed conventional SBM had a higher ($P \leq 0.02$) IOFC compared to pigs fed EESBM in the high feed cost, high revenue; high feed cost, low revenue; and low feed cost, low revenue scenarios. It is recommended that producers utilize their own current ingredient prices to economically compare these dietary options.

In conclusion, replacing conventional SBM with EESBM improved feed efficiency but due to increased feed cost without influencing gain, it was less economical as measured by IOFC. Also, the addition of benzoic acid improved feed efficiency but did not improve IOFC.

Table 1. Composition of soybean meal sources

	SBM	EESBM
Chemical analysis,[1] %		
DM	87.29	94.89
CP	45.45	43.20
Fat (acid hydrolysis)	1.20	7.73
Amino acids,[2] %		
Ala	1.95	1.85
Arg	3.16	3.10
Asx	5.15	4.95
Cys	0.59	0.61
Glu	8.16	7.75
Gly	1.88	1.84
His	1.14	1.13
Ile	2.02	1.93
Leu	3.44	3.28
Lys	2.83	2.73
Met	0.61	0.59
Met + Cys	1.20	1.20
Phe	2.30	2.19
Pro	1.74	2.29
Ser	2.29	2.21
Thr	1.82	1.76
Trp	0.66	0.52
Tyr	1.33	1.31
Val	2.07	1.99

[1]A composite sample of each treatment diet was collected from the feeder and later submitted to Midwest Laboratories (Omaha, NE) for proximate analysis.
[2]A composite sample of each treatment diet was collected from the feeder and later submitted to Ajinomoto (Chicago, IL) for amino acid analysis.
SBM = soybean meal. EESBM = extruded-expelled soybean meal.

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

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5		Phase 6	
Ingredient, %	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESBM
Corn	64.55	60.04	68.95	65.56	73.98	71.70	77.33	75.66	78.24	76.34	85.72	84.27
Soybean meal, 46% CP	22.60	---	18.35	---	13.50	---	10.30	---	9.65	---	12.35	---
Extruded expelled soybean meal, 43% CP[2]	---	27.04	---	21.67	---	15.74	---	11.94	---	11.55	---	13.75
Corn DDGS	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	---	---
Limestone	0.88	0.88	0.88	0.88	0.85	0.85	0.83	0.83	0.78	0.78	0.68	0.68
Monocalcium phosphate, 21%	0.34	0.35	0.32	0.33	0.28	0.28	0.22	0.23	0.13	0.13	0.32	0.33
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Lys-HCl	0.55	0.58	0.51	0.54	0.48	0.50	0.46	0.47	0.40	0.40	0.24	0.26
DL-Met	0.16	0.19	0.12	0.14	0.08	0.09	0.05	0.06	0.02	0.03	0.00	0.00
L-Trp	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	---	0.01
Thr[3]	0.24	0.24	0.21	0.21	0.19	0.19	0.16	0.16	0.14	0.13	0.08	0.08
L-Val	0.04	0.03	0.02	0.02	---	---	---	---	---	---	---	---
Vitamin and trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper chloride	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Phytase[4]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Benzoic acid[5]	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-
Total	100	100	100	100	100	100	100	100	100	100	100	100

Continue

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

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5		Phase 6	
	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESBM	SBM	EESB
Calculated analysis												
SID amino acids, %												
Lys	1.20	1.27	1.07	1.12	0.93	0.95	0.83	0.85	0.77	0.79	0.67	0.69
Ile:Lys	55	55	55	55	55	55	55	55	58	58	64	63
Leu:Lys	128	123	134	130	143	139	151	148	160	158	166	160
Met and Cys:Lys	58	58	58	58	58	58	58	58	58	58	60	58
Thr:Lys	63	63	63	63	64	64	64	64	65	65	66	66
Trp:Lys	17	17	17	17	17	17	17	17	17	17	17	17
Val:Lys	65	65	65	65	65	65	66	66	70	70	76	75
SID Lys:ME, g/Mcal	3.76	3.76	3.33	3.33	2.85	2.85	2.54	2.54	2.01	2.01	2.00	2.01
ME, kcal/lb	1,445	1,527	1,455	1,521	1,466	1,515	1,475	1,512	1,478	1,513	1,488	1,531
CP, %	19.02	19.57	17.34	17.76	15.42	15.66	14.16	14.31	13.90	14.17	13.01	13.00
Ca, %	0.60	0.60	0.58	0.58	0.55	0.55	0.52	0.52	0.48	0.48	0.48	0.48
Available P, %	0.30	0.30	0.29	0.29	0.28	0.28	0.26	0.26	0.24	0.24	0.24	0.24
Ca:P	1.99	2.00	2.00	2.01	2.00	2.00	2.00	2.00	2.01	2.01	2.00	2.01
Chemical analysis,[6] %												
CP	19.50	20.40	18.00	18.50	16.60	15.90	13.60	14.40	14.40	13.70	12.10	12.60
Fat (acid hydrolysis)	4.56	6.00	4.30	5.72	4.04	5.32	4.32	5.00	4.10	4.84	3.41	4.48

[1]Pigs were fed on a feed budget with phase 1, 2, 3, 4, and 5 provided at 42, 93, 108, 110, and 100 lb per pig, respectively. Phase 6 was provided for the remainder of the study.
[2]Lester Feed and Grain (Lester, IA).
[3]Thr Pro; CJ America Bio, Downers Grove, IL.
[4]Quantum Blue 5P (AB Vista, Marlborough, UK) was included at 2,000 FTU/kg and provided an estimated release of 0.12% for available P.
[5]VivoVitall (DSM Products, Parsippany, NJ) was added at 0.25%.
[6]A composite sample of each treatment diet was collected from the feeder and later submitted to Midwest Laboratories (Omaha, NE) for proximate analysis.
SBM = soybean meal. EESBM = extruded-expelled soybean meal.

Table 3. Main effects of extruded-expelled soybean meal and benzoic acid on growth performance, caloric efficiency, carcass characteristics, and carcass iodine value[1]

	SBM source				Benzoic acid[2]			
Item	SBM	EESBM	SEM	*P* =	None	Yes	SEM	*P* =
BW, lb								
d 0	69.3	69.0	1.03	0.58	69.2	69.1	1.03	0.85
d 51	171.8	171.8	1.55	0.99	173.3	170.2	1.55	0.03
Market weight	271.3	271.7	1.62	0.81	272.2	270.8	1.62	0.39
d 0 to 51								
ADG, lb	2.00	2.02	0.07	0.30	2.03	1.98	0.02	0.01
ADFI, lb	4.41	4.28	0.04	0.01	4.47	4.22	0.04	<0.001
F/G	2.21	2.12	0.01	< 0.001	2.20	2.13	0.01	< 0.001
d 51 to 109								
ADG, lb	2.05	2.06	0.02	0.37	2.04	2.07	0.02	0.06
ADFI, lb	6.42	6.32	0.04	0.06	6.34	6.41	0.04	0.14
F/G	3.14	3.07	0.02	< 0.001	3.11	3.09	0.02	0.33
Overall (d 0 to 109)								
ADG, lb	2.02	2.04	0.01	0.20	2.03	2.02	0.01	0.37
ADFI, lb	5.36	5.25	0.04	0.01	5.35	5.26	0.04	0.02
F/G	2.66	2.58	0.01	< 0.001	2.63	2.60	0.01	0.01
Removals, %	4.9	4.4	0.59	0.58	4.5	4.8	0.94	0.74
Mortality, %	3.7	3.3	0.60	0.60	3.7	3.3	0.60	0.60
Total removals and mortalities, %	8.6	7.8	0.84	0.48	8.2	8.1	0.74	0.94
Caloric efficiency, kcal ME/lb gain	3,902	3,910	15.4	0.62	3,934	3,878	15.4	< 0.001
Carcass characteristics								
HCW, lb	200.7	201.4	1.47	0.51	201.8	200.3	1.47	0.18
Yield, %	73.41	73.57	0.01	0.12	73.51	73.47	0.01	0.68
Iodine value	67.67	73.10	0.27	< 0.001	70.25	70.52	0.27	0.43

[1]A total of 2,162 pigs (initially 69.2 ± 4.9 lb) were used with 27 to 28 pigs per pen and 20 replications per treatment (40 replications per main effect) for a 109-day trial.
[2]VivoVitall (DSM Products, Parsippany, NJ) was added at 0.25%.
SBM = soybean meal. EESBM = extruded-expelled soybean meal.

Table 4. Main effects of extruded-expelled soybean meal and benzoic acid on economics[1]

Item	SBM source		SEM	$P =$	Benzoic acid[2]		SEM	$P =$
	SBM	EESBM			No	Yes		
Economics, $/pig placed								
Gain	190.45	191.57	1.78	0.63	191.14	190.88	1.78	0.91
Feed cost (Hi)[3]	70.44	73.18	0.65	0.002	71.67	71.95	0.65	0.74
Feed cost (Lo)[4]	42.86	45.03	0.39	< 0.001	43.59	44.30	0.39	0.17
Revenue (Hi)[5]	128.56	129.31	1.20	0.63	129.02	128.85	1.20	0.91
Revenue (Lo)[6]	78.56	79.02	0.73	0.63	78.85	78.74	0.73	0.91
IOFC (HiF-HiR)	58.12	56.13	0.67	0.02	57.35	56.90	0.67	0.58
IOFC (HiF-LoR)	8.12	5.84	0.31	< 0.001	7.17	6.79	0.31	0.26
IOFC (LoF-LoR)	35.70	34.00	0.41	0.001	35.26	34.44	0.41	0.11
IOFC (LoF-HiR)	85.70	84.28	0.86	0.20	85.43	84.55	0.86	0.42

[1]A total of 2,162 pigs (initially 69.2 ± 4.9) were used with 27 to 28 pigs per pen and 20 replications per treatment (40 replications per main effect) for a 109-day trial.
[2]VevoVitall, DSM Products, Parsippany, NJ.
[3]Feed cost (Hi): corn was valued at $6.72/bu ($240/ton); SBM at $420/ton, EESBM at $500/ton; DDGS at $260/ton; and benzoic acid at $1.15/lb.
[4]Feed cost (Lo): corn was valued at $3.36/bu ($120/ton); SBM at $280/ton, EESBM at $340/ton; DDGS at $160/ton; and benzoic acid at $1.15/lb.
[5]Revenue/pig placed (Hi) = (total gain/pig placed × 0.75) × $0.90.
[6]Revenue/pig placed (Lo) = (total gain/pig placed × 0.75) × $0.55.
SBM = soybean meal. EESBM = extruded-expelled soybean meal.

Results: Objective 4

For pig BW at time of loadout (12 h before harvest), pigs enrolled on the 24 h of feed withdrawal prior to harvest treatment were lighter ($P < 0.05$) than those on the 12 h withdrawal prior to harvest, both at first marketing and for overall marketing data, but not for the final marketing event (Table 1). This was a result of pigs having different weight gain on each marketing day, with pigs on the 12 h of feed withdrawal prior to harvest treatment having more gain ($P < 0.05$) than both other treatments. Additionally, pigs with 18 h feed withdrawal prior to harvest lost less weight ($P < 0.05$) than pigs with 24 h feed withdrawal prior to harvest when both marketing events were combined. For pig performance during the 14-d period between the first and final marketing event, there was no evidence of differences ($P \geq 0.10$) for any growth criteria between treatments.

For carcass characteristics, pigs at the final marketing event that had 12 h of feed withdrawal prior to harvest had increased ($P < 0.05$) HCW compared to those with 24 h of withdrawal prior to harvest (Table 2). When considering both marketing events, there was a tendency ($P = 0.055$) for a treatment effect with pigs having 12 h feed withdrawal prior to harvest having a 1.1 lb heavier HCW then those with 24 h feed withdrawal prior to harvest. When evaluating carcass yield using live weights for all pigs obtained 24 h prior to harvest, pigs in the final marketing group with 12 h of feed withdrawal before harvest had increased yield ($P < 0.05$) compared to pigs with 24 h of feed withdrawal before harvest. However, when evaluating carcass yield using live weights obtained at load out, 12 h prior to harvest, pigs with 24 h of feed withdrawal prior to harvest had increased yield ($P < 0.05$) compared with the other two treatments at the final marketing event and overall. At the first marketing event, pigs with 24 h of feed withdrawal prior to harvest had increased ($P < 0.05$) carcass yield compared to only the pigs on the 12 h feed withdrawal prior to harvest treatment. There were no differences in backfat, loin depth, and lean percent observed between treatments ($P > 0.10$).

Feed consumed and feed cost per pig on the final marketing and overall event were increased ($P < 0.05$) for pigs marketed with 12 or 18 h of feed withdrawal before harvest compared to those with 24 h feed withdrawal prior to harvest. However, in the first marketing event pigs marketed with 12 h feed withdrawal prior to harvest had increased ($P < 0.05$) feed consumption and feed cost compared to those with 18 h feed withdrawal, with pigs marketed with 24 h feed withdrawal prior to harvest having the lowest ($P < 0.05$) feed consumption and feed cost.

Table 1. Effect of feed withholding prior to harvest on growth performance[1]

	Feed withdrawal time before harvest[2]				
Item	12 h	18 h	24 h	SEM	*P* =
BW, lb					
24 h before harvest					
First marketing (d 0)	278.6	276.9	275.0	2.63	0.334
Final marketing (d 14)	280.6	280.4	280.3	2.68	0.994
Overall[3]	279.9	279.3	278.7	2.38	0.793
12 h before harvest (at time of loading on the truck)					
First marketing (d 0)	280.8[a]	275.9[ab]	273.2[b]	2.42	0.003
Final marketing (d 14)	281.3	280.2	276.6	2.81	0.153
Overall[3]	281.1[a]	278.8[ab]	275.6[b]	2.44	0.013
BW change, lb/pig[3]					
First marketing	2.50[a]	-1.09[b]	-1.90[b]	0.980	< 0.001
Final marketing	0.69[a]	-0.34[a]	-3.68[b]	0.440	< 0.001
Overall[4]	1.25[a]	-0.56[b]	-3.15[c]	0.490	< 0.001
Overall					
ADG, lb	2.18	2.16	2.10	0.072	0.528
ADFI, lb	6.27	6.27	6.27	0.064	0.997
F/G	2.93	2.95	3.04	0.075	0.307

[1]A total of 695 mixed sex pigs (initial BW 242.7 ± 1.36 lb) were used in a 14-d trial with 24 replications per treatment.

[2]The 3 treatments consisted of none, 6, or 12 h of feeder closure prior to loading on truck at both the first marketing event (2 weeks before final marketing) and final marketing event to achieve approximately 12, 18, and 24 h, respectively, of total feed withdrawal prior to harvest.

[3]Weighted average from the first and final marketing.

[4] Body weight difference between the 24 h and 12 h before harvest weight records.

Table 2. Effect of feed withholding prior to harvest on carcass characteristics and economics[1]

Item	Feed withdrawal time prior to harvest[2]			SEM	*P* =
	12 h	18 h	24 h		
Carcass characteristics					
HCW, lb[3]					
First marketing	203.7	203.3	204.2	0.91	0.573
Final marketing	206.3[a]	205.7[ab]	204.7[b]	0.38	0.010
Overall[4]	205.6	205.0	204.5	0.43	0.055
Carcass yield, %					
24 h before harvested					
First marketing	73.8	73.6	73.8	0.30	0.686
Final marketing	73.4[a]	73.2[ab]	72.9[b]	0.10	0.010
Overall[4]	73.5	73.3	73.1	0.20	0.099
12 h before harvested					
First marketing	73.1[b]	73.8[ab]	74.3[a]	0.30	0.012
Final marketing	73.2[b]	73.3[b]	73.8[a]	0.10	0.003
Overall[4]	73.2[b]	73.5[b]	73.9[a]	0.10	< 0.001
Backfat, in.[5]					
First marketing	0.53	0.52	0.52	0.008	0.572
Final marketing	0.55	0.54	0.56	0.007	0.259
Overall[4]	0.54	0.54	0.55	0.005	0.449
Loin depth, in.[5]					
First marketing	2.59	2.60	2.60	0.022	0.945
Final marketing	2.58	2.58	2.55	0.014	0.254
Overall[4]	2.58	2.59	2.57	0.012	0.492
Lean, %[5]					
First marketing	56.0	56.1	56.2	0.20	0.703
Final marketing	55.7	55.8	55.5	0.10	0.136
Overall[4]	55.8	55.9	55.7	0.10	0.372
Day of marketing feed consumed, lb/pig[6]					
First marketing	3.43[a]	1.76[b]	0.20[c]	0.212	< 0.001
Final marketing	2.47[a]	2.63[a]	0.30[b]	0.174	< 0.001
Overall[4]	2.78[a]	2.36[a]	0.27[b]	0.151	< 0.001
Feed cost, $/pig[7]					
First marketing	0.43[a]	0.22[b]	0.03[c]	0.026	< 0.001
Final marketing	0.31[a]	0.33[a]	0.04[b]	0.022	< 0.001
Overall[4]	0.35[a]	0.29[a]	0.03[b]	0.019	< 0.001
Economics					
Gross revenue, $/pig[8]					
First marketing	183.3	183.0	183.8	-	-
Final marketing	185.7	185.1	184.2	-	-
Overall[4]	185.0	184.5	184.1	-	-

[1]A total of 695 mixed sex pigs (initial BW 242.7 ± 1.36 lb) were used in a 14-d trial with 24 replications per treatment.
[2]The 3 treatments consisted of none, 6, or 12 h of feeder closure prior to loading on truck at both the first marketing event (2 weeks before final marketing) and final marketing event to achieve approximately 12, 18, and 24 h, respectively, of total feed deprivation prior to harvested.
[3]The 24 h BW before harvesting was used as a covariate for analysis of HCW.

[4]Weighted average from the first and final marketing.

[5]The HCW was used as a covariate for analysis of backfat, loin depth, and percentage lean.
[6]Feed used and feed cost was calculated using the feed consumed between the period of 24 h and 12 h before slaughter multiplied by the diet cost per lb.
[7]Diet cost was $0.125/lb.

[8]Gross revenue = HCW × carcass price. No statistical analysis was conducted.

Discussion: Objective 1

Although we collected all the known research studies, publication bias still needs to be kept in mind when interpreting the results of this literature review. Furthermore, most research was conducted in well-controlled research facilities that only utilized a small number of pigs per experiment; therefore, it may have limitations in representing the whole pig population. Moreover, compared to pigs in commercial settings, these research pigs were observed closely, experienced relatively little environmental stress (e.g., space allowance and temperature), and often had better health status and higher feed intake (nutrient intake) relative to pigs' requirements. Therefore, adding these feed additives may be more advantageous in pigs' diets in commercial settings where pigs are not under optimal conditions. Additionally, to utilize these results, the location of these studies should also be considered since some additives (e.g., DFM and essential oil) had large positive responses in some countries, but, in contrast, the US-based results showed neutral or negative responses. Lastly, even though the economics was not discussed in this review, the decision to include feed additives in the pig diets should consider return of investment based on the price and the magnitude of benefit to the feed additive. For example, a relatively small magnitude of G:F improvement may still be economical when provided by a relatively low-priced feed additive. Vice versa, a feed additive with relatively large magnitude of G:F improvement may not be economical if it has a relatively high price.

Thus, this literature review collected most of the available research on finishing pig feed additives to provide a descriptive analysis of the effects on growth and carcass performance and provides a database that can be further analyzed with advanced statistical methods, such as meta-analysis, with the goal of better understanding the effect of feed additives to improve the efficiency of swine production.

Discussion: Objective 2a

Although the literature provides numerous studies with L-Carnitine supplementation in swine diets, results are equivocal. This study provided no evidence that feeding L-Carnitine had an impact on growth performance, losses, or carcass characteristics when added to the late-finishing diet only. Although pigs fed L-Carnitine had carcasses that averaged 2 lb heavier, this improvement was not statistically different. Finally, added L-Carnitine improved performance in the early grow-finishing (58 to 104 body weight) phase compared to control. However, this effect was not detectable at market, with no impact on overall growth performance, removals and mortalities, or carcass characteristics when added for the entire grow-finishing period or just the 28 d prior to marketing.

Discussion: Objective 2b

Formic acid is frequently fed in the form of calcium, sodium, or potassium salts. Recently, there have been multiple studies feeding potassium diformate which resulted in increased growth performance parameters including improvements in average daily gain and feed efficiency. These data suggest that feeding increasing levels of sodium diformate improved ADG and ADFI after d 60 in the grow-finish period. However, due to the increased feed cost, it is currently not economical to feed sodium diformate throughout the entire grow-finish period. Therefore, further research is needed to investigate the addition of sodium diformate only in the late finisher (after ~180 lb) to understand if pigs will have similar improvements in growth performance while reducing overall feed cost to be more economical.

Discussion: Objective 3

The extrusion-expelling process results in a soybean meal with a greater fat content compared to conventionally processed soybean meal. This has the potential to improve growth performance in finishing pigs. Our findings revealed that replacing conventional SBM with EESBM improved feed efficiency but due to increased feed cost without influencing gain, it was less economical as measured by IOFC.

Acidifiers, such as benzoic acid, lower the pH of the gastrointestinal tract. While there is little commercial finishing data published, the addition of benzoic acid in our study improved feed efficiency but did not improve IOFC. Thus, the increase in feed cost with including benzoic acid was not offset by the improved feed efficiency. However, it is promising to find an acidifier that improved finishing feed efficiency and future work could potentially lead to cost justification with different feeding levels or regimens.

Discussion: Objective 4

There were no differences between the treatments on HCW and carcass yield first marketing event. However, in the final marketing event, differences were observed between the 12 h feed withdrawal prior to harvest and 24 h feed withdrawal prior to harvest treatments on HCW and carcass yield. Carcass yield was affected by time of feed withdrawal prior to harvest with greater yield for those with 12 h of feed withdrawal before harvest compared to those with 24 h of feed withdrawal prior to harvest at the final marketing event. Also, as expected, pigs with a longer time of feed withdrawal had reduced feed consumption and feed cost/pig on the day of marketing. Thus, savings in feed cost would have to offset the reduction in carcass weight to justify withholding feed greater than 12 h before harvest on the day of marketing.

Revised 10/2019