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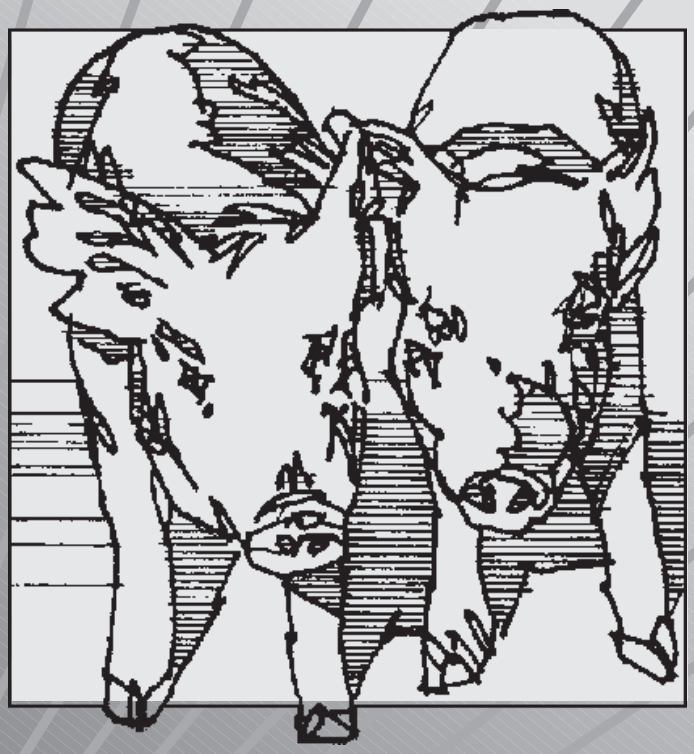

SWINE DAY 2004

Report of Progress 940

Swine Day 2004

FOREWORD

It is with great pleasure that we present to you the 2004 Swine Day 2004 Report of Progress. This report contains updates and summaries of applied and basic research conducted at Kansas State University during the past year. We hope that the information will be of benefit, as we attempt to meet the needs of the Kansas swine industry.

Editors, Swine Day 2004 Report of Progress,

Bob Goodband Mike Tokach Steve Dritz Joel DeRouchey

ABBREVIATIONS USED IN THIS REPORT

ADG	=	average daily gain	Gal	=	gallon(s)	mo	=	month(s)
ADFI	=	average daily feed intake	GE	=	gross energy	Fg	=	microgram(s)
avg	=	average	h	=	hour(s)		=	.001 mg
BW	=	body weight	in	=	inch(es)	N	=	nitrogen
cm	=	centimeter(s)	IU	=	international unit(s)	ng	=	nanogram(s)
CP	=	crude protein	kg	=	kilogram(s)		=	.001 Fg
CV	=	coefficient of variation	Kcal	=	kilocalorie(s)	no.	=	number
cwt	=	100 lb	lb	=	pound(s)	ppm	=	parts per million
d	=	day(s)	Mcal	=	megacalorie(s)	sec	=	second(s)
DM	=	dry matter	ME	=	metabolizable energy	SEW	=	segregated early weaning
EF	=	Fahrenheit	mEq	=	milliequivalent(s)			
F/G	=	feed efficiency	min	=	minute(s)	wk	=	week(s)
ft	=	foot(feet)	mg	=	milligram(s)	wt	=	weight(s)
ft^2	=	square foot(feet)	ml	=	cc (cubic centimeters)	yr	=	year(s)
g	=	gram(s)						

NCR, 1998. Nutrient Requirements of Swine. 10th Ed. National Academy Press, Washington, DC.

KSU VITAMIN AND TRACE MINERAL PREMIXES

Diets listed in this report contain the following vitamin and trace mineral premixes unless otherwise specified.

Trace mineral premix: each lb of premix contains 12 g Mn, 50 g Fe, 50 g Zn, 5 g Cu, 90 mg I, and 90 mg Se.

Vitamin premix: each lb of premix contains vitamin A, 2,000,000 IU; vitamin D_3, 300,000 IU; vitamin E, 8,000 IU; menadione, 800 mg; riboflavin, 1,500 mg; pantothenic acid, 5,000 mg; niacin, 9,000 mg; and vitamin B_{12}, 7 mg.

Sow add pack: each lb of premix contains choline, 100,000 mg; biotin, 40 mg; folic acid, 300 mg; and pyridoxine, 900 mg.

NOTICE

Trade names are used to identify products. No endorsement is intended, nor is any criticism implied of similar products not named.

Some of the research reported here was carried out under special FDA clearances that apply only to investigational uses at approved research institutions. Materials that require FDA clearances may be used in the field only at the rates and for the use specified in that clearance.

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BIOLOGICAL VARIABILITY AND CHANCES OF ERROR

Variability among individual animals in an experiment leads to problems in interpreting the results. Animals on treatment X may have greater average daily gains than those on treatment Y, but variability within treatments may indicate that the differences in production between X and Y were not the result of the treatment alone. Statistical analysis allows us to calculate the probability that such differences are from treatment rather than from chance.

In some of the articles herein, you will see the notation "$P<0.05$." That means the probability of the differences resulting from chance is less than 5%. If two averages are said to be "significantly different," the probability is less than 5% that the difference is from chance or the probability exceeds 95% that the difference resulted from the treatments applied.

Some papers report correlations or measures of the relationship between traits. The relationship may be positive (both traits tend to get larger or smaller together) or negative (as one trait gets larger, the other gets smaller). A perfect correlation is one (+1 or -1). If there is no relationship, the correlation is zero.

In other papers, you may see an average given as 2.5 ± 0.1. The 2.5 is the average; 0.1 is the "standard error." The standard error is calculated to be 68% certain that the real average (with unlimited number of animals) would fall within one standard error from the average, in this case between 2.4 and 2.6.

Using many animals per treatment, replicating treatments several times, and using uniform animals increase the probability of finding real differences when they exist. Statistical analysis allows more valid interpretation of the results, regardless of the number of animals. In all the research reported herein, statistical analyses are included to increase the confidence you can place in the results.

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FEEDING L-CARNITINE TO GESTATING SOWS ALTERS THE INSULIN-LIKE GROWTH-FACTOR SYSTEM IN CULTURED PORCINE EMBRYONIC MUSCLE CELLS ISOLATED FROM FETAL SKELETAL MUSCLE

A. T. Waylan, B. J. Johnson, D. P. Gnad[1], and J. C. Woodworth[2]

Summary

The objective was to determine the effects of L-carnitine on cell proliferation and on messenger RNA (mRNA) concentrations in the insulin-like growth factor (IGF) system. Cultured porcine embryonic myoblasts (PEM) were isolated from fetuses at mid-gestation from sows fed a common gestation diet with a 50-g top dress of 0 (control, n = 6) or 100 mg of L-carnitine (n = 6). Proliferation of PEM was evaluated at 36, 48, 60, and 72 h post-plating. Real-time quantitative PCR was used to determine growth factor mRNA concentrations in culture. The number of cells/cm^2 did not differ (P>0.05) from sows fed either diet, but the number of cells/cm^2 increased (P<0.05) between each time period. There was a treatment × time interaction (P = 0.05) for number of doublings. The number of doublings was greater (P<0.01) between 36 and 48 h for PEM isolated from dams fed L-carnitine, compared with that of the controls. When PEM were incubated with L-carnitine (n = 4) at six concentrations (3.125, 6.25, 12.5, 25, 50 and 100 μmol/L) and compared with a control, no proliferation differences were detected (P>0.05). There was no treatment difference (P>0.05) for the expression of IGF-I or insulin-like growth factor binding protein 5 (IGFBP-5). But PEM isolated from sows fed L-carnitine had decreased (P<0.05) IGF-II, IGFBP-3, and myogenin (61, 59, and 67%, respectively) mRNA concentrations compared with those of controls. These data suggest that L-carnitine influences the IGF system and myogenin, resulting in enhanced proliferation and delayed differentiation of porcine embryonic myoblasts. These results show that L-carnitine plays a role in regulating proliferation and differentiation of cultured porcine embryonic myogenic cells and that fetal muscle growth and development could be increased by feeding L-carnitine.

(Key Words: Insulin-like Growth Factor, Insulin-like Growth Factor Binding Protein, L-carnitine, Myoblasts, Pigs.)

Introduction

The IGF system is complex, including growth factors, receptors, and binding proteins, all of which are distinct gene products. The IGF-I and -II growth factors are important regulators of fetal and postnatal growth. Both of these factors mediate cell proliferation, differentiation, and metabolism *in vivo* and *in vitro*. Research has reported that in porcine fetuses, IGF-I and -II were expressed and produced primarily in muscle cells, supporting the hypothesis that these growth factors modulate fetal muscle growth. The IGF in serum are invariably found in association with IGF binding proteins (IGFBP), which serve as a storage reservoir, increase the half-life, and either inhibit or potentiate IGF actions. In addition, the IGFBP have biological effects that

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are independent of the two growth factors. Evidence of the IGF-independent action of IGFBP-3 was also reported in 1997; it was found that IGFBP-3 binds specifically to the type-V transforming growth-factor-β receptor. Proliferation of PEM is suppressed in the presence of IGFBP-3, and the amount of IGFBP-3 mRNA is reduced concurrently with the expression of myogenin, suggesting that IGFBP-3 also has a role in myogenic cell differentiation. At the initiation of C2 myoblast differentiation, IGFBP-5 mRNA reportedly increases, coinciding with the onset of myogenin. In addition, in 2002, the IGF-independent actions of IGFBP-5 were reportedly attributed to localization of IGFBP-5 in the nucleus and IGFBP-5 membrane-bound receptors. These data suggest that IGFBP can effect muscle growth and development at the local level, as well as have IGF-independent effects.

Kansas State University has previously reported that supplementing pigs with carnitine was beneficial for both growth traits and carcass muscling. In a gestation study, it was found that supplementing dams with L-carnitine increased circulating IGF-I concentrations at mid-gestation. Other researchers determined that injecting L-carnitine into streptozotocin-induced diabetic rats increased serum carnitine concentrations, total serum and liver IGF-I concentrations, and expression of liver IGF-I mRNA. L-carnitine had no effect on IGF-II concentrations or IGF-II mRNA.

It has long been established that the transport of long-chain fatty acids across the mitochondrial membrane into the mitochondrial matrix where β-oxidation occurs is L-carnitine-dependent. To our knowledge, however, there is no data representing how sow supplementation with L-carnitine affects PEM and the expression of IGF-system mRNA. In this experiment, L-carnitine was fed to gestating sows, and PEM were isolated from fetuses at mid-gestation. The main goal of this study was to use an *in vitro* model (PEM) to determine if there is a direct or indirect effect of L-carnitine on embryonic cell proliferation and if mRNA concentrations of the IGF-system are affected.

Procedures

Animals and Feeding Protocol. Twelve fourth-parity sows (PIC, Franklin, KY; C 22 sows; BW = 552.7 lb) were artificially inseminated (PIC; 327 MQ) 12, 24, and 36 h after the onset of estrus. Sows were randomly allotted to one of two dietary treatments. All sows were fed once daily 4.4 lb of a gestation diet based on corn-soybean meal (Table 1) and received a 50-g top dress containing either 0 (control, n = 6) or 100 mg of L-carnitine (Carniking 10; 10% L-carnitine; Lonza, Inc., Fairlawn, NJ) from d 1 to 54.5 of gestation. Day 1 of gestation was considered 12 h after the first insemination. Sows were allowed *ad libitum* access to water.

Table 1. Composition of Diet (As-fed Basis)

Item	Gestation Diet, %
Corn	85.06
Soybean meal (47% CP)	10.89
Mono-calcium phosphate	1.85
Limestone	1.05
Salt	0.50
Minerals and vitamins	0.65
	100.0
Calculated Analysis, %	
Lysine	0.55
Crude protein	12.30
ME, Mcal/lb	1.50
Calcium	0.80
Phosphorus	0.70
Fat	3.64
Fiber	1.67

Eighteen hours before hysterectomy, sows were transported from Kansas State University Swine Teaching and Research Center to the

surgery suite on campus where sample collections were performed 24 h after the last feeding.

A hysterectomy was completed on each sow between d 55 and 59 of gestation. Sows were anesthetized and the uterus was removed. Once the uterus was removed, the muscle layers and skin were closed with absorbable sutures. Fetal pigs were immediately removed under aseptic conditions and rapidly transported to a laminar flow hood where myogenic cells were isolated. Isolated cells were suspended in solution, frozen at -80°C, and stored in a liquid nitrogen tank.

Cell Culture. Proliferation rates of the porcine embryonic myoblasts isolated from each of the sows were determined at 36, 48, 60 and 72 h post-plating. Growth factor and myogenin mRNA concentrations were determined from the same breakouts, at 96 h post-plating.

To establish cultures from frozen stocks, rapidly thawed cell suspensions were diluted with 25 mL of Dulbecco's Modified Eagle Medium containing 10% (v/v) fetal calf serum. One mL and 10 mL of cell solution were plated on 4-well plates (2-cm^2-wells) and 100-mm dishes, respectively, coated with Basement Membrane Matrigel (diluted 1:27 (v/v) in DMEM. All cultures were maintained at 37°C, 5% CO_2, 95% air in a water-saturated environment. After a 24-h attachment period, the 100-mm plates were rinsed twice with 5 mL of DMEM. Plates were refed with DMEM containing 10% FCS (0.5 mL/2-cm^2 well or 7 mL/100-mm plate). At the desired post-plating time, [^{3}H]thymidine (1 μCi/mL final concentration; NEN Life Science, Boston, MA) was added to the culture media on the 4-well plates and allowed to incubate at 37°C for 3 h. After radioisotope exposure, cells were rinsed three times with 0.5 mL cold DMEM, and 5% cold trichloroacetic acid (TCA) was added. Four random microscope fields were counted and averaged for each well to determine the number of PEM. Plates were incubated at 4°C overnight and then rinsed again with cold TCA. [^{3}H]thymidine incorporation into cellular DNA was measured by dissolving cell material in 0.5 mol/L sodium hydroxide and counting in a scintillation counter. All data were averaged from triplicate wells.

Direct Effects of L-carnitine on PEM *In Vitro*. A separate set of experiments evaluating the range of 3.125 to 100 μmol/L L-carnitine were undertaken to determine any potential direct effects of L-carnitine on PEM. To establish cultures from frozen stocks, the same procedure as previously described was followed, with differences being 1-mL of cell solution was plated on a 24-well plate (2-cm^2 wells) coated with Basement Membrane Matrigel (diluted 1:27 (v/v) in DMEM). After a 24-h attachment period, the wells were aspirated and refed with 0.5 mL DMEM containing 10% FCS. At 48-h post-plating, the wells were rinsed three times with 0.5 mL DMEM, and 0.5 mL of desired test media was added to each well. To make stock solutions, L-carnitine was dissolved in DMEM. The L-carnitine stock solutions were diluted with DMEM containing low serum (2% v/v swine serum) to make test media (3.125, 6.25, 12.5, 25, 50, and 100 μmol/L). In addition, a control media was made with DMEM replacing the addition of a L-carnitine stock solution. At 72 h post-plating, the wells were incubated for 3 h with [^{3}H]thymidine. The remaining steps of the radioisotope exposure were completed as described previously. All data points were averaged from triplicate wells.

Isolation of RNA and Real-time Quantitative PCR. At 96-h post-plating, total RNA was isolated from cells on the 100-mm plates. The concentration of RNA was determined by absorbance at 260 nm. TaqMan reverse transcription reagents and MultiScribe Reverse Transcriptase were used to produce complimentary DNA (cDNA) from 1 μg of total

RNA. Random hexamers were used as primers in cDNA synthesis.

Real-time quantitative PCR was used to measure the quantities of IGF-system mRNA, relative to the quantity of 18S ribosomal RNA (rRNA) in total RNA isolated from cultured cells. Measurement of the relative quantity of cDNA was carried out by using TaqMan Universal PCR Master Mix, 900 nmol/L of the appropriate forward and reverse primers, 200 nmol/L of appropriate TaqMan detection probe, and 1 µl of the cDNA mixture. The porcine-specific forward and reverse primers and TaqMan detection probes were synthesized according to published GenBank sequences for the specific genes of interest.

Relative quantities of target mRNA were normalized to 18S rRNA with the eukaryotic 18S rRNA endogenous control. Assays were performed in an ABI Prism 7000 sequence detection system, using thermal cycling parameters recommended by the manufacturer (50 cycles of 15 s at 95ºC and 1 min at 60ºC). Relative expression of the porcine genes was normalized with the 18S endogenous control by using the Δ-CT method, and is expressed in relative units. Titration of 18S, IGF-I, IGF-II, IGFBP-3, IGFBP-5, and myogenin primers against increasing amounts of cDNA gave linear responses with slopes of -3.3 to -3.9.

Statistical Methods. A single-factor (0 or 100 mg of L-carnitine) experiment in a completely randomized design was conducted. Statistical analyses for cell-proliferation data and gene-expression levels were performed with the Mixed procedure of SAS, with the dam as the experimental unit. The statistical model for the proliferation data included the fixed effects of treatment and time and the random effect of animal. The statistical model for the gene-expression data included the fixed effect of treatment and the random effect of animal. The Mixed procedure of SAS was also used for the analysis of the PEM L-carnitine titration experiment, and the L-carnitine concentration was the fixed effect with assay as the random effect. All main-effect and interaction means were separated ($P<0.05$), unless otherwise noted, by using the Least Significant Difference procedure when the respective F-tests were significant.

Results and Discussion

To determine the effect of feeding L-carnitine to gestating sows, plasma L-carnitine concentrations were determined. At mid-gestation, circulating total carnitine was 30% greater ($P<0.05$) in the sows supplemented with L-carnitine compared with that of the control sows (27.20 and 20.97 µmol/L, respectively). This indicates that supplemental L-carnitine increases circulating carnitine concentrations.

The average number of cells/cm^2 did not differ ($P>0.05$) between PEM from sows fed a control diet or fed a diet with supplemental L-carnitine (Figure 1, Panel A); as expected, however, there was a time effect ($P<0.05$). As the number of hours post-plating increased, the average number of cells/cm^2 also increased ($P<0.05$) between each of the evaluated time-periods. At the conclusion of the experiment (72 h), there were 11% more cells in the L-carnitine treatment than in the control.

An indicator of PEM proliferation is the rate of [^{3}H] incorporation. Incorporation of [^{3}H]thymidine/cell was not altered ($P>0.05$) by treatment at 36, 48, 60, or 72 h post-plating (Figure 1, Panel B).

There was a treatment x time interaction ($P = 0.05$) for the number of doublings (Figure 1, Panel C). There was a 1.5-fold increase ($P<0.01$) in the number of doublings between 36 and 48 h for the PEM isolated from dams fed L-carnitine, compared with the number of doublings in PEM from control dams. At the remaining time intervals of 48/60 and 60/72 h,

there were no differences (P>0.05) detected between the two treatments.

Porcine embryonic myoblasts isolated from a commercial gilt fed a diet containing no supplemental L-carnitine were used to evaluate the direct effects of L-carnitine. No differences (P>0.05) were observed for the percentage change in counts per minute between the six L-carnitine concentrations and the control (Figure 2).

Total RNA was isolated from the PEM cultures at 96 h post-plating. The expression of IGF-I, IGF-II, IGFBP-3, IGFBP-5, and myogenin mRNA were determined (Table 2). There was no difference (P>0.05) between treatments for the expression of IGF-I or IGFBP-5. But PEM isolated from sows fed L-carnitine had decreased (P<0.05) mRNA concentrations of IGF-II, IGFBP-3, and myogenin (61, 59, and 67%, respectively) compared with those of PEM isolated from control sows.

Little is known about the effects of L-carnitine on the IGF system in primary porcine muscle cell cultures. Two different models were used to determine the direct and indirect effects of L-carnitine on PEM proliferation. A diet with no supplemental L-carnitine was fed to a gilt, and then PEM were isolated from fetal muscle and used to determine the direct effects of adding L-carnitine *in vitro*. The indirect effects of L-carnitine were evaluated by isolating PEM from sows either supplemented with L-carnitine or fed a control diet during gestation. The increased concentrations of circulating L-carnitine in the gestating sows supplemented with L-carnitine suggests that the L-carnitine is being absorbed and entering the blood stream. Previous research at Kansas State University also observed that sows supplemented with L-carnitine had increased concentrations of circulating carnitine.

At the initiation of the experiment, there was not a treatment difference in the number of cells at 36 h. At each succeeding time increment, however, a numerical increase was observed for the number of PEM isolated from sows supplemented with L-carnitine and there were 11% more cells in the L-carnitine treatment than the control at 72 h. In support of the increased number of cells at the conclusion of the experiment, there was a 1.5-fold increase in the number of doublings between 36 and 48 h post-plating in the L-carnitine cells, compared with the number of doublings in cells from the controls. This suggests that PEM isolated from sows fed L-carnitine have an initial increased rate of proliferation and that this alteration in proliferation early during the culture period is resulting in numerical increases in total cells at the conclusion of proliferation. These data support earlier reports that offspring from dams supplemented with L-carnitine had a larger cross-sectional area in the semitendinosus muscle. A concern with primary cultures is that non-myogenic cell types, which could have shorter doubling times, are present and can make interpretation of proliferation data difficult. Results of the differentiation studies (data not shown) suggest that the changes in cell proliferation were a result of treatment affecting only myogenic cells, indicating that the increased rate of proliferation in cultures derived from L-carnitine is not due to the potential for greater proliferation of non-myogenic cells overtaking these cultures.

Even though there was not a treatment effect, the uptake of [^{3}H]thymidine in the PEM isolated from sows supplemented with L-carnitine continued to increase up to 60 h post-plating, but only up to 48 h in the control cultures. At the last evaluated time (72 h), a numerically greater uptake of [^{3}H]thymidine remained in the L-carnitine cultures. This is consistent for the observed numerical increase in number of cells in the L-carnitine cultures compared with the number of cells in the controls at the end of the assay.

To determine if the effects of L-carnitine on the proliferation data were a direct effect of L-carnitine, another experiment using PEM isolated from a commercial pregnant gilt was conducted by incubating the PEM with differing L-carnitine concentrations. At the six L-carnitine concentrations evaluated, no consistent differences between the concentrations and the control were found for the incorporation of [^{3}H]thymidine into the PEM. There was no trend amongst the L-carnitine concentrations for [^{3}H]thymidine incorporation. This indicates that L-carnitine is most likely not directly affecting the proliferation of the PEM, and that the increased number of doublings from the L-carnitine treatment is a result of an indirect effect. Another explanation comes from a previous study in which it was reported that human skeletal muscle in culture had two different affinities for carnitine uptake: a high-affinity uptake between 0.5 and 10 μmol/L and a low-affinity uptake between 25 and 200 μmol/L carnitine. Therefore, in the current study, the lack of a trend between the proliferation rate of the PEM and the L-carnitine concentration may be caused by the differing affinities for carnitine uptake by the PEM.

The effect of feeding L-carnitine on carcass muscle characteristics has been studied extensively. Research has reported that feeding sows 100 mg/d of L-carnitine resulted in a 90% increase in maternal circulating IGF-I concentration at mid-gestation compared with that of control sows. But little is known about the interactive effects of L-carnitine and the growth factors or about the singular effects of L-carnitine on porcine fetal muscle growth and development. It was hypothesized that L-carnitine may be influencing the IGF system. Many cell types, including myogenic cell lines, have been shown to synthesize both IGF and IGFBP. Previous studies have identified that multiple components of the IGF system affect the proliferation and differentiation of PEM. In the current study, growth factor, binding protein, and myogenin mRNA concentrations were determined in PEM at 96 h in culture. Even though not significant, the expression of IGF-I was increased 82% in PEM isolated from dams supplemented with L-carnitine, compared with expression in non-supplemented sows. High concentrations of IGF-I increased [^{3}H]thymidine incorporation into primary porcine cell cultures, and IGF-I has been shown to extend proliferation of muscle cells. Therefore, the observed numerical increase of IGF-I mRNA in L-carnitine cultures suggests that L-carnitine increases local IGF-I production. The increased IGF-I availability in the L-carnitine cultures explains why the rate of [^{3}H]thymidine incorporation/cell continued to increase for an additional 12 h, compared with that of the controls. In addition, there was an accumulation of cyclin D1 (10-fold increase) by mid-G_1 phase of the cell cycle in satellite cells isolated from IGF-I transgenic mouse muscle, in comparison with accumulations in muscle from control littermates. This suggests that IGF-I enhances the replicative life span of myogenic cells, which is also observed in the current study because of the increased doublings and the total number of cells at the end in the L-carnitine cultures.

During fetal muscle development, the progression of events in myogenesis is that mononucleated proliferating myoblast exit the cell cycle and fuse to form multi-nucleated cells or myotubes. Myoblasts withdrawal from the cell cycle activates transcription factors (MyoD family regulatory factors), with one being myogenin, which is expressed at the onset of myogenesis. Myogenin is not expressed in proliferating myoblasts, but only under differentiation conditions, and is often used as an early marker of differentiation in muscle cell cultures.

In addition to the transcription factors, IGF-II has been found to modulate fetal growth and development. Myoblasts themselves can secrete IGF-II, which can itself induce differentiation, or IGF-II can promote differentiation through paracrine and endo-

crine mechanisms. In C2 myoblasts, IGF-II mRNA concentrations rise dramatically (4-fold) during differentiation, compared with those expressed during proliferation. It is suggested that the autocrine secretion of IGF-II is essential for the process of terminal differentiation in these cells because the rate of differentiation correlates with the level of expression of IGF-II. In the current study, IGF-II mRNA concentrations were decreased 61% and myogenin was decreased 67% in L-carnitine PEM, compared with those of the control PEM. Taken together, the IGF-II and myogenin data suggest that there is a delay in the onset of terminal differentiation in PEM isolated from sows fed L-carnitine, thus allowing these cells to remain in a proliferative stage longer. Furthermore, the numerical difference in IGF-I mRNA would be consistent with cells having increased proliferative capacity.

The IGF binding proteins are known for their ability to bind growth factors to increase their stability and half-life, as well as to modulate the action of the growth factors. In this study, the mRNA concentrations of IGFBP-3 and IGFBP-5 were reduced 59% and 50%, respectively, in the PEM isolated from the sows supplemented with L-carnitine, compared with their concentrations in the control sows. This suggests that there would be less binding capacity in PEM from supplemented sows, and that the action of IGF-I may be enhanced, ultimately increasing cell proliferation. The decrease in IGFBP-3 mRNA concentrations in L-carnitine cultures, compared with those of the controls, indicates that the L-carnitine cultures were at the initiation of differentiation at 96 h in culture. It has been reported that in extensively fused cultures (144 h in culture) there was a three-fold increase in IGFBP-3 mRNA concentration, compared with that of the nonfused cultures. This also supports the current proliferation data, that L-carnitine cultures proliferate longer and, hence, would have lower IGFBP-3 mRNA concentrations. The decrease in the expression of IGFBP-5 in the PEM isolated from the L-carnitine treatment also supports that there would be increased proliferation in this treatment because IGFBP-5 is secreted within 12 h of the onset of differentiation in myoblasts (14) and is associated with terminal differentiation.

We have shown that L-carnitine influences muscle growth through an indirect mechanism, as evidenced by the prolonged proliferation and suppressed differentiation in the PEM isolated from sows supplemented with L-carnitine. The increased proliferation rates and the 82% increase in IGF-I mRNA are reported characteristics specific for myogenic cells. The observed expression of EGFBP-3 is further evidence in the current study that the prolonged proliferation was not the result of contaminating non-myogenic cells because IGFBP mRNA is not produced by fibroblasts.

In summary, the enhanced IGF-I concentration and decreased IGFBP-3 could potentiate IGF-I actions on proliferation. At the same time, IGF-II and myogenin mRNA concentrations are reduced, resulting in suppressed differentiation. These results, in combination with the developmental pattern of the growth factors, show that L-carnitine plays a role in regulating proliferation and differentiation of cultured porcine embryonic myogenic cells, and that fetal muscle growth and development could be increased.

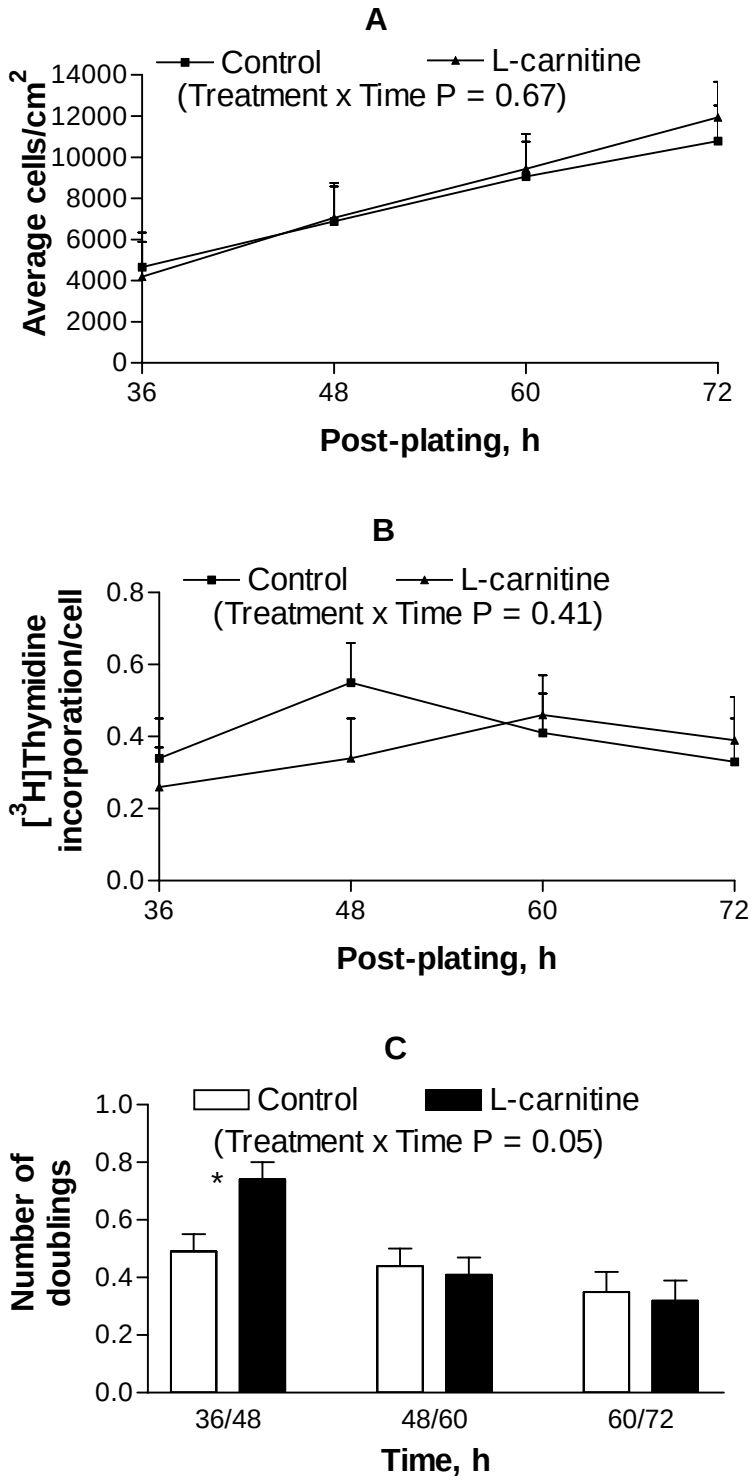

Figure 1 The Average Number of Cells per cm^2 (panel A), [^{3}H]thymidine Incorporation per Cell (panel B), and the Number of Doublings (panel C) at Designated Times Post-plating (36, 48, 60, 72 h post-plating) in Porcine Embryonic Myoblasts (PEM) Isolated from Dams Fed a Control Diet or Supplemented 100 mg/day of L-carnitine. Values are means and SEM, n = 6 per treatment. There was a treatment x time interaction (P = 0.05) for the number of doublings. The number of doublings was greater (P < 0.05) between 36 and 48 h for the PEM isolated from dams fed L-carnitine, compared with those of the controls, and the asterisk indicates this difference.

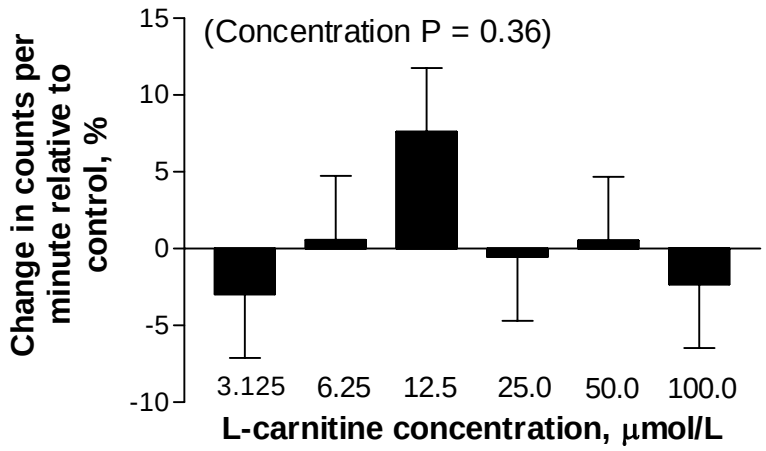

Figure 2 The Effect of Differing Concentrations of L-carnitine in 2% Swine Serum (v/v) and Dulbecco's Modified Eagle Medium on the Percentage Change of Counts per Minute in Comparison with those of the Control for Porcine Embryonic Myoblasts (PEM). The PEM were incubated with the L-carnitine for 24 h, between 48 and 72 h post-plating. Values are means and SEM, n = 4 per concentration.

Table 2. Growth-Factor Messenger RNA Content in Porcine Embryonic Muscle Cells at 96 h of Culture[a]

Gene	Control	L-carnitine	SEM	P-value
IGF-I	3.47	6.31	1.89	0.31
IGF-II	21.68	8.44	3.54	0.02
IGFBP-3	5.62	2.30	0.90	0.03
IGFBP-5	22.49	11.24	4.85	0.13
Myogenin	4.02	1.33	0.79	0.04

[a]Gene expression levels are expressed in relative units; n = 6 per treatment.

USING REGUMATE TO CONTROL ESTRUS IN SWINE

D. L. Davis

Summary

Altrenogest, marketed for use in horses as Regumate, is a synthetic progestin that is marketed for use in pigs as MATRIX. It effectively regulates the occurrence of estrus in randomly cycling gilts if it is provided for 14 or more days at a daily dose of 15 mg/day. It is important to assure that each gilt receives her full dose; otherwise problems of cystic follicles and reduced fertility may be observed.

(Key Words: Pigs, Estrous Synchronization, Altrenogest.)

Introduction

It has long been recognized that gilts constitute a challenge for swine breeding herds. Gilts are expensive, they occupy valuable space, and the occurrence of estrus in gilts may not fit the production schedule. Production managers often view gilts with skepticism, and most would opt for eliminating the first pregnancy cycle and going right to the second parity if there was a method to do it.

Gilts are unavoidable, however, and make up 20 to 50% of breeding herds. The gilt pool provides a management system to minimize problems with gilt breedings, but the unpredictable occurrence of estrus in gilts creates additional labor and housing costs. Many production units opt for one or both of the following strategies: 1) house excess gilts to make up for shortages on some weeks, 2) check estrus but not breed at first detected estrus, thus allowing service to occur at a second or later postpubertal estrus, and providing some ability to predict future occurrence of estrus and plan for excesses and shortfalls in the availability of gilts in a particular week.

Researchers began attempting to regulate the estrous cycle of pigs at least 50 years ago. The development of prostaglandin $F_2\alpha$ products provided a method to regulate the estrous cycle of several species of farm animals, but not pigs. The mechanism of prostaglandin products is to regress the corpora lutea (CL), thus causing an early entry into proestrus, but the pig CL are resistant to the effects of prostaglandin $F_2\alpha$ until very late in their cycle and a practical method to use them has not been forthcoming. Some have inseminated gilts, then used prostaglandin $F_2\alpha$ to induce abortion followed by a fertile heat, but this is too cumbersome for routine use.

Soon after synthetic progestins became available, there were many attempts to administer these to pigs as a part of the daily feed for the purpose of estrous synchronization. To be useful, the progestins should group the estruses of gilts at a reliable interval after the end of progestin treatment, and provide fertility equal to untreated controls. Experiments with these initial products revealed two things:

1) with the progestins tested, a relatively low dose would suppress estrus, but often resulted in follicular cysts, rather than the growth of normal follicles and ovulation.

2) doses high enough to suppress the formation of follicular cysts led to poor synchronization of estrus and even lack of estrus. Faulty sperm transport was also a problem.

Among the initial progestins tested was melengesterol acetate (MGA), a product used to suppress estrus in feedlot heifers and as a part of some synchronization protocols in cattle. Results of the earlier trials clearly indicate that MGA will not be useful for synchronizing estrus in pigs.

In the middle 1970s, the first experiments were conducted at Abbott Laboratories with a progestin that proved unique in its ability to synchronize estruses in gilts. The progestin has been identified by several names, including allyl trenbolone and altrenogest, and has been marketed for use in horses as Regumate for some time. Recently, Intervet, Inc. has secured approval to market the formulation long used in horses for use in pigs. The product, MATRIX, is supplied as a solution containing 0.22% (2.2 mg/mL) altrenogest. The label indicates a treatment administering 6.8 mL (15 mg altrenogest) per gilt once daily for 14 consecutive days.

Gilts should be treated on an individual-animal basis by top-dressing MATRIX on a portion of each gilt's daily feed allowance. The rest of this paper will describe the research leading to this recommendation and will explain the mechanism of action of altrenogest for regulating estrous cycles in gilts.

Effectiveness of Altrenogest

When post-pubertal (cycling) gilts are treated with altrenogest for 14 or 18 days, followed by cessation of altrenogest treatment, there is a grouping of estruses between 4 and 10 days after the last altrenogest treatment. The peak in occurrence of first estrus is generally from 5 to 7 days after last treatment. The data in Figure 1 illustrate the estrous response in cycling control gilts and those treated with altrenogest. This response has proven to be repeatable, and the estruses of 85% or more of cycling gilts can be scheduled to a 5-day interval, with the majority of estruses occurring in a 2- to 3-day interval.

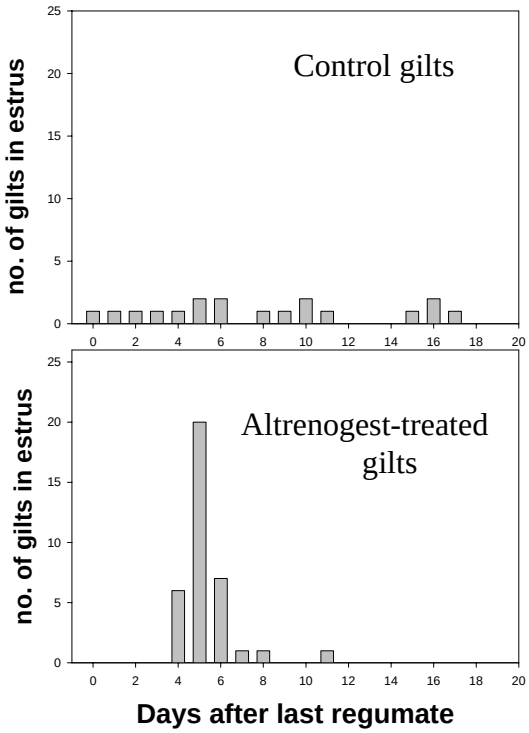

Figure 1. Occurrence of Estrus in Cycling Gilts Not Treated (control) or Treated with Altrenogest (15 mg/day) for 18 Days. Day 0 is the last day of altrenogest treatment.

Required Dose to Regulate Estrous

A well designed, two-stage study was conducted at five locations in the United States to identify the daily dose of altrenogest required to synchronize estrus. Gilts that were known to be having regular estrous cycles were treated with increasing doses of altrenogest daily for 18 consecutive days. The data indicated that daily doses less than 12.5 mg/day result in increased incidence of cystic follicles. Many gilts with cysts at the lower daily doses had multiple cysts and experienced failures to conceive.

These studies resulted in the recommendation that 15 mg/day be provided to each gilt to provide a small margin of safety. Reliably administering this dose requires treatment of

individual gilts. Attempts to feed altrenogest to groups of gilts have met with poor synchrony of estrus, reduced numbers of gilts exhibiting estrus, and with reduced fertility.

Recommended Duration of Treatment

The initial studies evaluated gilts provided altrenogest for 18 days. In theory, however, 14 days should be adequate because the CL of gilts regress on days 14 to 16 of their estrous cycles. Comparison of 14- and 18-day durations of treatment is presented in Figure 2.

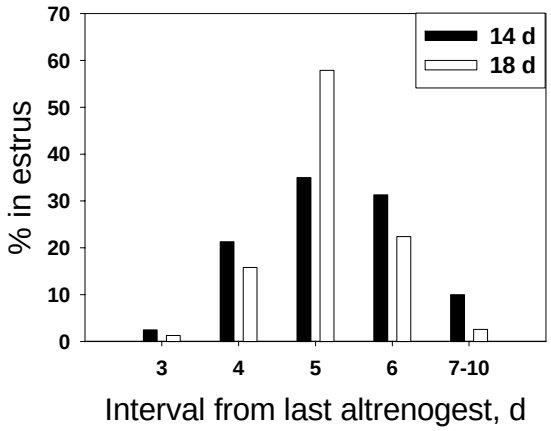

Figure 2. Effect on the Onset of Estrus of Treating Gilts with Altrenogest (15 mg/day) for 14 or 18 Days. The last day of altrenogest treatment is day 0. (Drawn from data in Stevenson and Davis, J. Anim. Sci. 55:119-123, 1982).

The onset of estrus may be somewhat more synchronous with the 18-day treatment but for practical applications 14 days is adequate.

Fertility After Altrenogest Treatment

Numerous trials have evaluated the conception rate, farrowing rate, and litter size after treating gilts with altrenogest. The results indicate no effects of altrenogest on these traits. In some experiments there is a slight improvement in litter size for altrenogest-treated gilts. This may result from the more predictable time of estrus onset, and thus more ideal timing of insemination. In some experiments ovulation rate is increased by altrenogest treatment but this has not been consistently observed.

Conclusions

Altrenogest, the active ingredient in MATRIX, has been adequately evaluated in controlled experiments and field observation and, if administered in a way that provides 15 mg daily for 14 days, it is effective for regulating the estruses of cycling gilts such that 85% or more will express estrus 4 to 10 days after last treatment with altrenogest.

COMPARISON OF HEART GIRTH OR FLANK-TO-FLANK MEASUREMENTS FOR PREDICTING SOW WEIGHT

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Summary

In previous Swine Day Reports we have demonstrated that feeding sows in gestation on the basis of body weight and backfat thickness is more precise and economical than methods of feeding based on visual observation of body-condition score. To simplify the weight and backfat procedure, we have estimated sow weight based on the correlation between heart girth (circumference of the sow measured behind the front legs) and weight. The objective of this study was to determine if a different sow measurement, flank to flank, would be as accurate as the heart-girth measurement. Sows were weighed and measured behind the front legs for heart girth or in front of the back legs for flank-to-flank measurement, and regression equations to estimate sow weight were developed. A total of 605 sows from three farms were used for the girth measurement. A total of 306 sows from two farms were used for the flank-to-flank measurement. The heart-girth equation was: weight, lb = 21.54 × heart girth, in – 684.76. The flank-to-flank measurement was: weight, lb = 26.85 × flank-to-flank, in – 627.93. The average residual was 30.8 lb for the heart girth measurement and 31.4 lb for the flank-to-flank measurement. Both of these measurements provide a reasonable weight estimate that can be used to determine weight categories for more accurately feeding gestating sows.

(Key Words, Heart Girth, Pigs, Prediction Equations, Sows, Weight.)

Introduction

Determining the proper feeding rate for gestating sows in commercial farms has been challenging. Body-condition score often has a poor relationship with the backfat value of the sow. Also, because 80 to 90% of the energy requirement is for maintenance in gestation, determining the energy requirement of the sow is important. Research has demonstrated that the maintenance requirement is closely related to sow weight. But sow weight unfortunately is not easy to determine in farms because of the inability to easily and efficiently weigh sows. If methods to estimate sow weight could be developed, feeding programs could more easily account for the differences in maintenance requirements of sows of differing body weights. The goal of this project was to develop regression equations to estimate sow weight from girth or flank measurements, and to determine whether these equations could accurately estimate sow body weight.

Procedures

Sows from three farms were used in this project. Girth was measured on sows at all three farms, and flank measurements were taken on sows at two of the farms. In total,

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[2]Food Animal Health and Management Center.

605 sows were used for the girth measurements and 306 sows were used for the flank measurements. On all farms, sows were removed from the gestation stall and weighed on a platform scale. The girth and flank measurements were obtained while sows were in their gestation stall. Girth was measured by using a cloth tape measure. Girth was defined as the circumference of the sow immediately behind the front legs and in front of the first mammary glands (Figure 1). Flank-to-flank measurement was taken immediately in front of the hind legs by using the cloth tape measure. This measurement was defined as the measurement from the bottom of the flank on one side to the bottom of the flank on the other side, with the cloth tape being placed over the top of the hip (Figure 2).

Regression equations to predict body weight based on girth or flank measurement were developed by using the Proc Mixed procedure of SAS. Farm (three farms for girth and two farms for flank to flank) was included in the statistical model as a random variable to account for farm-to-farm variability. Residuals were calculated for both girth and flank-to-flank measurements to estimate the accuracy of the equations. The residuals were calculated as the absolute value of the difference between predicted weight using the developed regression equations and actual weight measured with the scale.

Results and Discussion

Both the girth and the flank-to-flank measurements were positively related with body weight (Figures 3 and 4). The heart-girth equation was: weight, lb = 21.54 × heart girth, in – 684.76. The flank-to-flank measurement equation was: weight, lb = 26.85 × flank-to-flank, in – 627.93.

The average residual was 30.8 lb for the heart-girth measurement and 31.4 lb for the flank-to-flank measurement. The median residual was 25.7 for girth and 26.0 for flank-to-flank measurement, which indicates that 50% of the sows had their weight predicted within 26 lb of their actual weight by using either equation (Table 1), and 75 and 90% of the sows had their weight predicted within 43 and 66 lb, respectively, of their actual weight. Comparison of the residuals indicates that the girth or flank measurements have similar accuracy.

As discussed in the introduction, one of the goals of developing a method to estimate weight is to be able to feed sows more accurately in the gestation barn. To do this, we need to categorize sows into weight categories. The weight categories shown in Table 2 have been used for our sow gestation feeding programs. The girth and flank-to-flank equations from this experiment were used to develop the categories to match each weight category. The relationship between the weight and measurement category, and the actual weights and measurements, are shown in Figures 5 and 6.

Another way to view this data is to calculate the percentage of sows that are placed in the correct weight category after measuring girth or flank to flank and the percentage of sows that are over- or under-estimated for weight and placed in the wrong category (Table 3). For girth, 66% of the sows were placed in the correct category, with 19.8% and 13.7% being under- and over-estimated for weight, respectively. Only one of the 605 sows was two categories off of the correct estimate. All other sows that were under- or over-estimates were within one category of the correct weight. For flank-to-flank measurements, 72% of the 306 sows were placed in the correct weight category, with 13 and 14% being under- and over-estimated, respectively. This analysis indicates that using either method to estimate weight would correctly classify similar numbers of sows. In agreement with the analysis of residuals, this indicates that the accuracy of the two methods is similar.

Girth measurement has been used for many years, across many species, as a rapid and easy measure to estimate body weight. For sows housed in a gestation crate, however, the girth measurement is not easily obtained because the front of the sow is not easily accessible. With most crate designs, the rear of the sow is easily accessible to obtain the flank-to-flank measurement. Therefore, the flank-to-flank measurement can be obtained faster, with less risk of operator injury and with the same accuracy as girth measurement, although either method should provide a more accurate estimation of body weight than visual estimation would.

Figure 1. The Heart-Girth Measurement.

Figure 2. The Flank-to-Flank Measurement.

Table 1. Residual of Sow Weight (Difference Between Predicted and Actual Weight)

Percentile	Girth, lb	Flank-to-flank, lb
25th	13.6	14.2
50th	25.7	26.0
75th	42.6	42.9
90th	65.0	66.3

Table 2. Weight Categories and Corresponding Girth and Flank-to-flank Measurements

Weight, lb	Girth, in	Flank to flank, in
< 325	< 46.9	< 35.5
325 to 400	47.0 to 50.4	35.6 to 38.0
400 to 475	50.5 to 54.0	38.1 to 41.0
475 to 550	54.1 to 57.5	41.1 to 44.0
> 550 lb	> 57.6	> 44.1

Table 3. Percentage of Sows that were Accurately Categorized or Under- or Over-estimated for Weight Category

	Weight Category					
	1	2	3	4	5	Total
Girth measurement						
Correct category	1.7%	10.7%	12.4%	13.7%	27.9%	66.4%
Underestimated	- - -	2.3%	3.0%	5.6%	8.9%	19.8%
Overestimated	1.7%	3.5%	2.8%	5.8%	- - -	13.7%
Total	3.3%	16.5%	18.2%	25.1%	36.9%	100.0%
Flank-to-flank measurement						
Correct category	- - -	3.9%	13.7%	21.9%	32.7%	72.2%
Underestimated	- - -	- - -	1.0%	2.3%	10.1%	13.4%
Overestimated	- - -	3.6%	6.5%	4.2%	- - -	14.4%
Total		7.5%	21.2%	28.4%	42.8%	100.0%

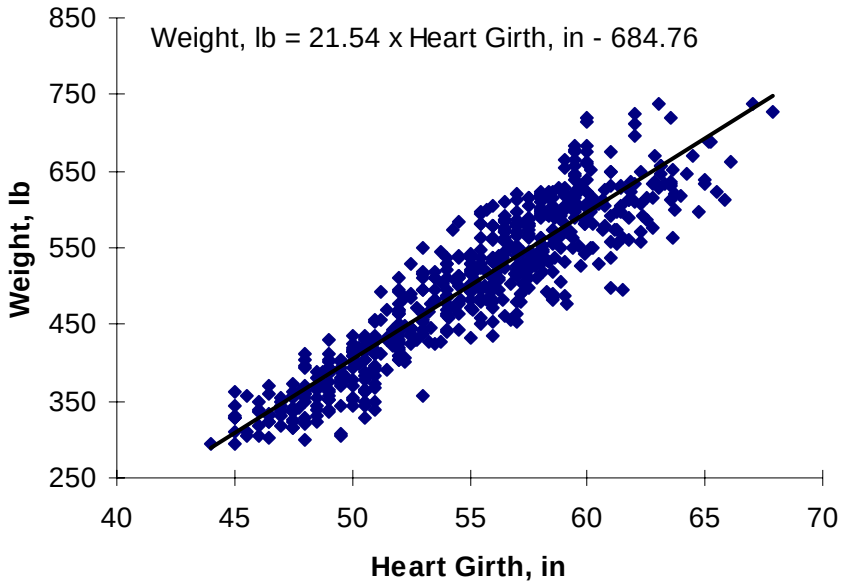

Figure 3. Relationship Between Heart Girth and Sow Weight (605 sows from 3 farms).

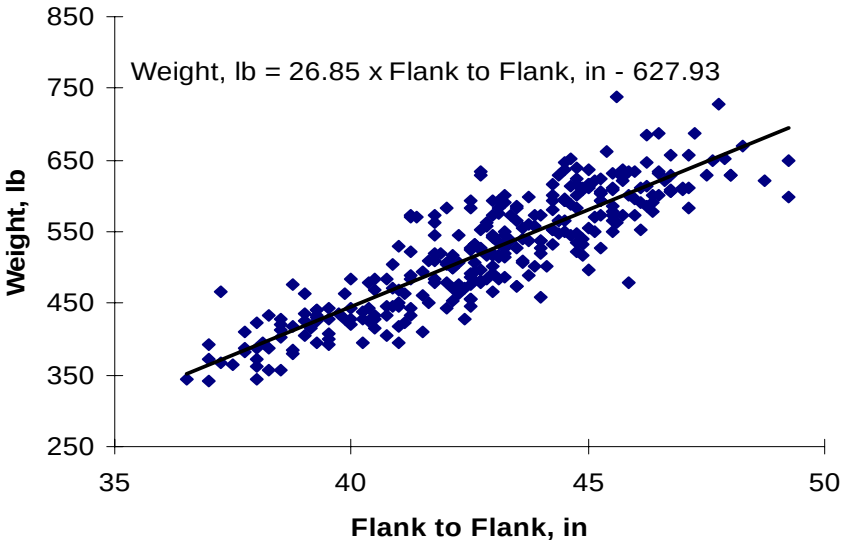

Figure 4. Relationship Between Flank-to-flank Measurement and Sow Weight (306 sows from 2 farms).

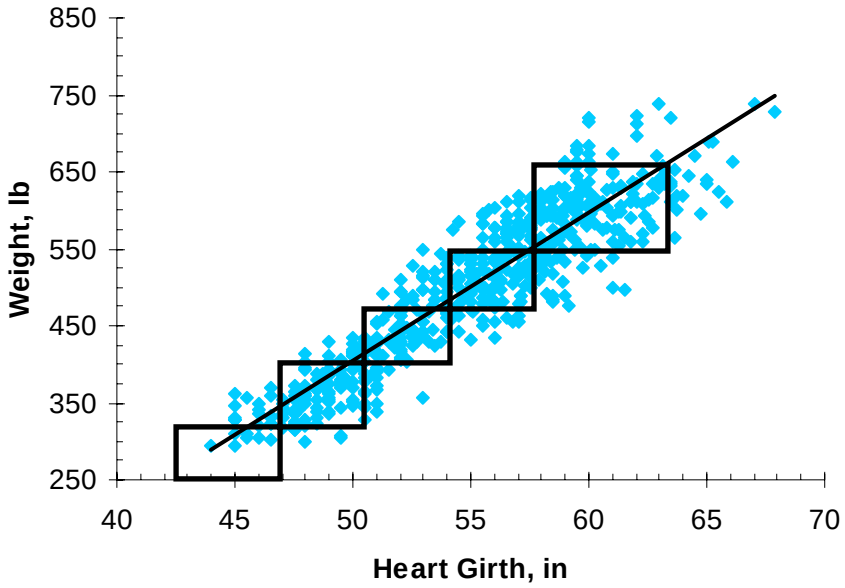

Figure 5. Weight Categories for Sow-Gestation Feeding Program by Using Heart Girth.

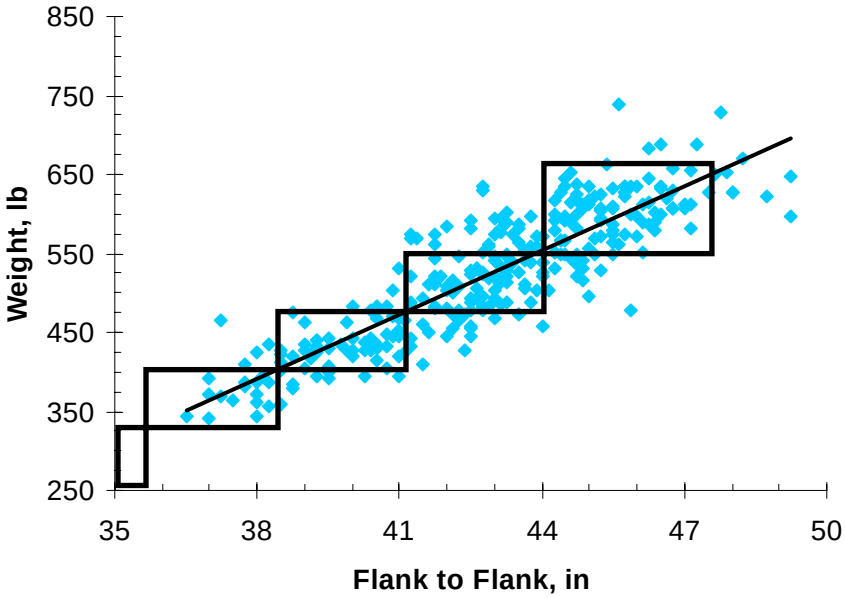

Figure 6. Weight Categories for Sow-Gestation Feeding Program by Using Flank-to-flank Measurement.

Swine Day 2004

EFFECTS OF WEANING TIME (PM OR AM) ON NURSERY-PIG GROWTH PERFORMANCE

C. R. Neill, M. D. Tokach, J. L. Nelssen, R. D. Goodband, J. M. DeRouchey, S. S. Dritz[1], J. E. Minton, C. N. Groesbeck, K. R. Lawrence, C. W. Hastad, R. O. Gottlob, B. M. Hildabrand, and T.E. Burkey

Summary

An experiment was conducted to evaluate the effects of weaning time (PM or AM) on nursery-pig growth performance. The objective was to see how weanling pigs would adjust to the nursery environment if sows were removed from the farrowing crates 12 h before moving pigs into the nursery. Each sow and litter was randomly allotted to a wean time (PM or AM). Half of the litters had their sow removed on Thursday afternoon (PM), leaving the pigs in the farrowing crate. The other litters remained on the sow until weaning on Friday morning (AM). All pigs, both PM and AM treatments, were moved from the farrowing house to the nursery on Friday morning. A total of 542 weanling pigs (PIC 327L × C22) from 50 litters were used in the experiment. Pigs were approximately 21 d of age with an average initial body weight of 13.4 lb. All pigs were weighed in the farrowing house in the morning of the day that half of the sows were removed from the farrowing house that afternoon. Pigs were again weighed on d 7, 14, 21, and 28 after weaning to determine ADG, ADFI, and F/G. There was an improvement in F/G ($P<0.002$) from d 0 to 7 for pigs that were left on the sow until actual weaning in the AM, but this was because litters were weighed on Thursday morning and their pigs were allowed to nurse for 2 h longer than pigs in those litters whose sows were removed Thursday afternoon (PM), which caused gut loss in the pigs. Removing sows from the farrowing house early (PM) had no benefit or detrimental effect on ADG, ADFI, or F/G for the overall 28-d study.

(Key Words: Nursery Pigs, Pigs, Wean Time.)

Introduction

Weanling pig acclimatization to the nursery environment is very important to ensure good growth performance. The faster pigs can transition from sow's milk to dry feed, the better the pig performance will be. Removing the sow from the litters 12 h before moving pigs to the nursery may increase the pig's hunger and, therefore, encourage a faster start on feed. The PM weaning might also allow farm managers to find more quickly pigs that don't start eating feed than with traditional morning weaning (AM). It would also allow sows to be moved into the breeding barn in the afternoon and not miss being fed the morning of weaning. The objective of this study was to evalu-

[1]Food Animal Health and Management Center.

ate the effects of wean time (PM or AM) on the growth performance of weanling pigs.

Procedures

A total of 542 pigs (initial BW = 13.4 lb and approximately 21 d old) were blocked by weight. Each sow and litter was randomly allotted to a wean time (PM or AM). A total of 25 litters were weaned on Thursday afternoon (PM), with the pigs remaining in the farrowing crates. The other 25 sows were allowed to remain with their litters all night. On Friday morning (AM), litters from both the PM and AM treatments were moved into the nursery. All pigs from the litters went on trial. A total of 271 pigs were used for each treatment (PM and AM). All pigs were fed a corn-soybean meal diet in a two-phase feeding program. All pigs were weighed in the farrowing house in the morning of the day that half of the sows were removed in the afternoon. The pigs were weighed again on d 7, 14, 21, and 28 to determine ADG, ADFI, and F/G. Statistical analysis was conducted according to SAS v. 8.1.

Results and Discussion

The litters that were weaned on Friday morning (AM) had improved F/G ($P < 0.002$) from d 0 to 7. This was because all of the litters were weighed on Thursday morning, and litters weaned Friday (AM) were allowed to nurse for 12 h longer than pigs in those litters that had sows removed Thursday PM, causing gut loss in the pigs. There was no effect of wean time (PM or AM) observed for ADG, ADFI, or F/G for the overall trial (d 0 to 28). Therefore, our study indicated that wean time (PM or AM) did not affect nursery-pig performance.

Table 1. Effects of Weaning Time (PM or AM) on Nursery-Pig Growth Performance[a]

	Wean Time[a]			
Item	PM	AM	SE	P-value
Day 0 to 7				
ADG, lb	0.31	0.32	0.05	0.84
ADFI, lb	0.37	0.35	0.02	0.24
F/G	1.30	1.14	0.05	0.003
Day 0 to 14				
ADG, lb	0.57	0.57	0.02	0.93
ADFI, lb	0.63	0.62	0.02	0.72
F/G	1.12	1.09	0.02	0.24
Day 0 to 28				
ADG, lb	0.85	0.86	0.02	0.68
ADFI, lb	1.11	1.11	0.02	0.82
F/G	1.29	1.29	0.01	0.50
Final weight, lb	37.2	37.3	0.5	0.82

[a]A total of 542 nursery pigs (PIC L 327L × C22) were blocked by weight. Fifty sows and litters were randomly assigned to a weaning time (PM or AM). Twenty-five sows were removed from their farrowing crates in the PM, leaving the pigs in the farrowing crates. The other 25 sows remained in the farrowing house with their litters. All pigs were moved in the nursery at the same time. All pigs in each litter were put on trial.

Swine Day 2004

GROWTH PERFORMANCE OF NURSERY PIGS FED BIOSAF YEAST ALONE OR IN COMBINATION WITH IN-FEED ANTIMICROBIAL[1]

B. M. Hildabrand, C. R. Neill, T. E. Burkey, S. S. Dritz[2], B. J. Johnson and J. E. Minton

Summary

A total of 210 pigs were used in a 28-d growth study to evaluate the effects of feeding the combination antibiotic neomycin and oxytetracycline (Neo-Terra), different rates of BIOSAF yeast (0.15% or 0.3%), and the combination of Neo-Terra and BIOSAF in nursery diets. Overall, pigs fed the diet containing both Neo-Terra and 0.15% BIOSAF had greater ADG and ADFI than did pigs fed the control diet and pigs fed either concentration of BIOSAF alone ($P<0.05$). Furthermore, over the entire trial, pigs fed the diet containing both Neo-Terra and BIOSAF also tended to have greater ADG and ADFI than did pigs fed only Neo-Terra ($P = 0.15$). Pigs fed Neo-Terra had greater ADG and ADFI than did pigs fed the control diet and the diet containing 0.15% BIOSAF, but both ADG and ADFI were similar between pigs fed Neo-Terra and pigs fed 0.3% BIOSAF. Whereas BIOSAF fed alone did not significantly improve growth performance over that of control pigs, pigs fed the diet combining both Neo-Terra and 0.15% BIOSAF had a 16% improvement in ADG, compared with that of pigs fed the control diet, and had a trend for an improvement in ADG, compared with that of pigs fed the diet containing Neo-Terra without added yeast. Thus, in nursery settings where Neo-Terra will be added, addition of 0.15% BIOSAF to diets could enhance growth performance. The overall growth performance of pigs fed 0.3% BIOSAF yeast was intermediate to that of pigs fed the control diet and pigs fed the diet containing Neo-Terra. Additional research will be required to determine definitively if a rate at, or close to, 0.3% BIOSAF can be added to nursery diets to approach growth performance observed with Neo-Terra.

(Key Words: Antimicrobials, BIOSAF, Neomycin, Oxytetracycline, Nursery Pigs, Pigs.)

Introduction

Dietary antibiotics continue to be used in nursery-pig diets to improve growth performance. Because of growing concerns regarding the long-term sustainability of this practice, however, there is an active search for alternatives. Live yeasts are a class of feed additives that may hold promise. Yeasts are hypothesized to alter the intestinal microbiota in the pig by interacting with potential pathogens in the gut. Certain classes of bacteria adhere to yeast cell walls and, in doing so, decrease the likelihood of pathogen binding and colonization of the gut wall.

BIOSAF is a heat-stable yeast product that improved ADG compared with diets without antibiotics when fed in pelleted nursery diets

[1]The authors thank Saf Agri, a division of the Lesaffre Group, Minneapolis, MN, for partial funding of the experiment.

[2]Food Animal Health and Management Center.

at 0.2% (Swine Day 1998 report). But the growth response of nursery pigs to BIOSAF has not been evaluated in comparison with added antibiotic, or when added at lower concentrations in combination with antibiotic.

Procedures

A total of 210 weaned pigs (initial BW 13.4 lb) were used in a 28-d study to evaluate BIOSAF yeast alone, and in combination with antibiotic, on pig growth performance. There were five treatments, with seven pigs per pen and six pens per treatment. Pigs were blocked by weight and sex and assigned randomly within block to one of five dietary treatments. Phase 1 diets were fed from d 0 to 14, and Phase 2 diets were fed from d 15 to 28 (Table 1). All diets were fed in meal form, were based on corn-soybean meal, and were formulated to provide 1.55% lysine, 0.82% calcium, and 0.48% available phosphorus in phase 1 or 1.51% lysine, 0.78% calcium, and 0.38% available phosphorus in phase 2. The negative-control diet contained no added antibiotic or yeast, and the positive-control diet contained the antibiotic combination Neo-terra (140 g/ton neomycin sulfate and 140 g/ton oxytetracycline HCl). Two diets contained BIOSAF yeast at 0.15 or 0.3%, and a fifth diet contained the combination of 0.15% BIOSAF and Neo-Terra. All diets were formulated without growth-promoting concentrations of copper sulfate or zinc oxide.

Growth-performance data, including ADG, ADFI, and feed efficiency (F/G), were calculated by weighing pigs and feeders at weekly intervals throughout the experiment.

Results and Discussion

Growth-performance data are shown in Table 2. During the first two weeks (d 0 to 14), pigs fed the diet containing the combination of Neo-Terra plus BIOSAF had greater ADG than did pigs fed the control diet or the diet with 0.15% BIOSAF ($P<0.05$). In addition, ADG was greater for pigs fed Neo-Terra alone than for pigs fed BIOSAF at 0.15% ($P<0.05$). No other differences were detected for ADG, ADFI, or F/G during the first two weeks.

In the final two weeks of the trial (d 15 to 28), pigs fed the diet containing both Neo-Terra and BIOSAF had greater ADG and ADFI than did pigs fed the control diet or pigs fed either rate of BIOSAF alone ($P<0.05$). The ADG of pigs fed the combination diet, though not significantly different, actually tended to be greater than that of pigs fed Neo-Terra ($P=0.12$). During this same period, ADG and ADFI of pigs fed Neo-Terra was greater than those of pigs fed the control diet or of pigs fed the diet with 0.15% BIOSAF ($P<0.05$). No differences among treatments were detected for feed efficiency during the final two weeks of the trial.

Overall (d 0 to 28), pigs fed the diet containing the combination of Neo-Terra and BIOSAF had greater ADG and ADFI than did pigs fed the control diet or pigs fed either rate of BIOSAF alone ($P<0.05$). Furthermore, over the entire trial, pigs fed the diet containing both Neo-Terra and BIOSAF also tended to have greater ADG and ADFI than pigs fed only Neo-Terra had ($P=0.15$). Pigs fed Neo-Terra had greater ADG and ADFI than did pigs fed the control diet and the diet containing 0.15% BIOSAF. Over the entire trial, however, ADG and ADFI did not differ for pigs fed Neo-Terra and pigs fed 0.3% BIOSAF.

As expected, the addition of Neo-Terra increased ADG and ADFI in weanling pigs. Unexpectedly, Neo-Terra and BIOSAF seemed to act synergistically to enhance ADG and ADFI when combined in weanling pig diets. Thus, in production settings in which the decision has been made to include Neo-Terra in nursery diets, pig growth performance might be enhanced by addition of 0.15% BIOSAF. At present, it is not clear whether

the trend we observed for synergism between BIOSAF and Neo-Terra will be observed with other antibiotics. The overall growth performance of pigs fed 0.3% BIOSAF yeast was intermediate between that of pigs fed the control diet and pigs fed the diet containing Neo-Terra. Additional research will be required to determine definitively if a concentration at, or close to, 0.3% BIOSAF can be added to nursery diets to approach growth performance observed with Neo-Terra.

Table 1. Basal Diet Composition (As-fed Basis)[a]

	Days of Experiment	
Ingredient, %	0 to 14	15 to 28
Corn	47.50	55.95
Soybean meal, 46.5% CP	27.00	37.40
Spray dried whey	15.00	---
Select manhaden fish meal	5.00	---
Choice white grease	3.00	3.00
Monocalcium phosphate, 21% P	0.80	1.40
Limestone	0.50	1.00
Salt	0.20	0.30
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-Threonine	0.15	0.15
Lysine HCl	0.30	0.30
DL-Methionine	0.15	0.125
Calculated Analysis		
Lysine, %	1.55	1.45
Isoleucine:lysine ratio, %	74	64
Leucine:lysine ratio, %	146	129
Methionine:lysine ratio, %	40	33
Methionine & cystine:lysine ratio, %	69	59
Threonine:lysine ratio, %	79	65
Tryptophan:lysine ratio, %	21	18
Valine:lysine ratio, %	82	71
ME, kcal/lb	1,478	1,506
Crude protein, %	26.4	21.4
Ca, %	1.09	0.85
Available P, %	0.63	0.42

[a]Corn was removed from the basal diet and replaced with neomycin and oxytetracycline (0.7 %) to provide 140 g/ton of each antimicrobial and BIOSAF yeast (0.15 % or 0.3 %) to achieve the experimental diets detailed in the Procedures.

Table 2. Growth Performance of Nursery Pigs[a]

	Dietary Treatments[b]						
	Control	Neo-Terra	BIOSAF 0.15 %	Neo+BIOSAF 0.15 %	BIOSAF 0.3 %	SEM	P value
Weeks 1 to 2							
ADG, lb	0.48[c,d]	0.54[d,e]	0.44[c,g]	0.57[e,f]	0.50[d,f,g]	0.03	0.05
ADFI, lb	0.56	0.58	0.51	0.63	0.59	0.03	0.08
F/G	1.16	1.08	1.18	1.09	1.17	0.03	0.13
Weeks 3 to 4							
ADG, lb	1.13[c]	1.24[d,e]	1.10[c]	1.30[d]	1.18[c,e]	0.05	0.01
ADFI, lb	1.49[c]	1.65[d,e]	1.48[c]	1.71[d]	1.58[c,e]	0.07	0.01
F/G	1.32	1.33	1.32	1.32	1.33	0.02	0.79
Weeks 1 to 4							
ADG, lb	0.81[c]	0.88[d,e]	0.78[c]	0.94[d]	0.84[c,e]	0.04	0.01
ADFI, lb	1.03[c,d]	1.11[e,f]	1.00[c]	1.17[e]	1.08[d,f]	0.05	0.01
F/G	1.27	1.25	1.27	1.25	1.29	0.02	0.43

[a]A total of 210 pigs (seven pigs per pen and six pens per treatment).
[b]Control = diet containing no added antibiotic or yeast; Neo-Terra = diet with 140 g/ton neomycin sulfate and 140g/ton oxytetracycline HCl; BIOSAF 0.15 = diet with BIOSAF yeast at 0.15 %; Neo+BIOSAF 0.15 = Neo-Terra diet with BIOSAF at 0.15 %; BIOSAF 0.3 = diet with BIOSAF yeast at 0.3%.
[c,d,e,f,g]Means having different superscript letters within a row differ ($P<0.05$).

EVALUATING OREGANO OIL AS A GROWTH ENHANCER IN NURSERY PIG DIETS

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Summary

A total of 224 nursery pigs (PIC L 327L × C22) initially 12.9 ± 3.0 lb and 21 d of age were used in a 28-d feeding trial. The objective of our study was to evaluate the effects of oregano oil, with or without an in-feed antimicrobial. Oregano oil is a plant extract derived from the Greek herb, *Origanum vulgare*. It has been speculated to have antimicrobial-like activity. There were four dietary treatments in a 2 × 2 factorial. Diets consisted of a negative control (without an antibiotic or oregano oil), the control diet plus neomycin/oxytetracycline (140 g/ton), the control diet plus oregano oil, or the control diet with both neomycin/oxytetracycline and oregano oil. The oregano oil (5%) was added to an inert carrier (95%) to make a premix that was added to the diet at 2 lb/ton in phase 1 (d 0 to 14) and 1 lb/ton in phase 2 (d 14 to 28). During the 28-d trial, neomycin/oxytetracycline improved ADG, ADFI and F/G. Pigs fed dietary treatments containing neomycin/oxytetracycline had the heaviest average weights at the end of the trial. Adding oregano oil to nursery pig diets did not improve ADG, ADFI, or F/G during the 28-d trial.

(Key Words: Nursery Pigs, Neomycin/Oxytetracycline, Oregano, Pigs.)

Introduction

Finding and evaluating new feed additives and substitutes for antibiotics is an ongoing task in the swine industry. Several ingredients have been proposed to partly or fully replace antibiotics in swine diets, such as milk products, spray-dried animal plasma, zinc oxide, copper sulfate, diet acidifiers, egg immunoglobulins, mannan oligosaccharide, probiotics, fructo-oligosaccharide, spices, botanicals, essential oils, and herbs. Oregano oil is a plant extract derived from the Greek herb, *Origanum vulgare*. It has been shown to have antimicrobial-like activity. This makes oregano a natural feed additive with the potential to enhance palatability of swine feed and to improve ADG and F/G in pigs. Therefore, the objective of this trial was to compare the effects of oregano oil and the in-feed antimicrobial combination of neomycin/oxytetracycline on growth performance in nursery pigs.

Procedures

A total of 224 weanling pigs with an initial average weight of 12.8 pounds (PIC L 327L × C22) were blocked by weight and randomly allotted to one of four dietary treatments. The dietary treatments were arranged in a 2 × 2 factorial. Pigs were fed a negative-control diet (without in-feed antimicrobials or oregano

[1]The authors thank Ralco-mix Products, Inc., Marshall, MN, for supplying the oregano oil used in this study.

oil), the control diet with neomycin (140 g/ton) and oxytetracycline (140 g/ton), the control diet with oregano oil, and the control diet with both neomycin/oxytetracycline and oregano oil. Oregano oil premix was added at 2 lb/ton in phase 1 and 1 lb/ton in phase 2.

There were seven pigs per pen and eight pens per treatment. Pigs were housed at the Kansas State University Swine Teaching and Research Center's environmentally controlled nursery, with one self feeder and one nipple waterer in each pen to allow ad libitum access to feed and water. The experimental diets were fed in a meal form and in two phases. The phase 1 diet (Table 1) was fed from d 0 to 14, and the phase 2 diet was fed from d 14 to 28. Pigs were weighed on d 0, 7, 14, 21 and 28 to determine ADG, ADFI, and F/G. Data were analyzed as a factorial arrangement, with main effects of neomycin/oxytetracycline and oregano oil in a randomized complete-block design.

Results and Discussion

There were no neomycin/oxytetracycline by oregano oil interactions observed (Table 2). Adding oregano did not improve growth performance from d 0 to 14 or overall (d 0 to 28), but ADG, ADFI, and F/G were improved ($P<0.01$) for the pigs fed neomycin/oxytetracycline in both the d 0 to 14 and d 0 to 28 periods. Pigs fed neomycin/oxytetracycline were also the heaviest ($P<0.01$) at the end of the trial. Oregano oil was not effective in enhancing growth performance in this experiment.

Table 1. Diet Composition (As-fed Basis)

Item	Phase 1[a]	Phase 2
Ingredient, %		
Corn	48.10	59.97
Soybean meal (46.5% CP)	29.00	34.98
Spray dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium phosphate (21% P)	1.15	1.60
Limestone	0.70	1.10
Salt	0.33	0.35
Vitamin premix with phytase	0.25	0.25
Trace mineral premix	0.15	0.15
L-Threonine	0.13	0.15
L-Lysine HCl	0.30	0.30
DL-Methionine	0.15	0.15
Corn starch[b]	1.00	1.00
Calculated Analysis		
Lysine, %	1.55	1.45
Isoleucine:lysine ratio, %	74	64
Leucine:lysine ratio, %	146	129
Methionine:lysine ratio, %	40	33
Methionine&Cystine: lysine ratio, %	69	59
Threonine;lysine ratio, %	79	65
Tryptophan:lysine ratio, %	21	18
Valine:lysine ratio, %	82	71
ME, kcal/lb	1.478	1,506
Crude protein, %	26.4	21.4
Ca, %	1.09	0.85
Available P, %	0.63	0.42

[a]Phase 1 diets were fed in meal form from d 0 to 14 after weaning. Phase 2 diets were fed in meal form from d 14 to 28 after weaning.

[b]Oregano oil premix (2 lb/ton in phase 1 and 1 lb/ton in phase 2) or neomycin/oxytetracycline (140 g/ton) was added at the expense of corn starch to provide the experimental diets.

Table 2. Growth Performance Effects of Feeding Oregano Oil Post-Weaning[ab]

Item	Negative Control	Neomycin/ oxytetracycline	Oregano Oil	Oregano oil and Neomycin/ oxytetracycline	SE	P-Value		
						Oregano Oil	Neomycin/ oxytetracycline	Neomycin/ Oxytetracycline X Oregano Oil
Initial Weight, lb	12.86	12.92	12.89	12.84	1.17	0.80	0.88	0.57
Day 0 to 14								
ADG, lb	0.50	0.63	0.52	0.62	0.03	0.67	0.0001	0.40
ADFI, lb	0.59	0.67	0.60	0.66	0.03	0.87	0.0001	0.61
F/G	1.19	1.07	1.16	1.08	0.02	0.52	0.0001	0.39
Day 0 to 28								
ADG, lb	0.78	0.93	0.81	0.92	0.03	0.61	0.0001	0.25
ADFI, lb	1.05	1.20	1.07	1.19	0.05	0.98	0.0001	0.54
F/G	1.35	1.29	1.31	1.29	0.02	0.24	0.01	0.15
Final Weight. lb	34.70	39.03	35.67	38.59	1.86	0.65	0.0001	0.22

[a]A total of 224 nursery pigs with seven pigs/pen with eight pens/treatment were used.
[b]Oregano oil premix was added at 2 lb/ton from d 0 to 14 and 1 lb/ton from d 14 to 28. Neomycin/oxytetracycline was added at 140g/ton.

THE EFFECTS OF DIFFERENT FEED-GRADE ANTIBIOTICS ON GROWTH PERFORMANCE OF WEANLING PIGS IN A RESEARCH ENVIRONMENT

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Summary

A total of 168 weanling pigs (initially 13.8 lb and 21 ± 3 d of age, PIC) were used to determine the effects of different feed-grade antibiotics on nursery-pig performance. Pigs were fed one of four experimental diets: control with no antibiotics; or the control diet with added Denagard/CTC (35 g/ton Denagard™, 400 g/ton Chlortetracycline); Neo-Terramycin® (140 g/ton Neomycin Sulfate, 140 g/ton Oxytetracycline HCl); or Mecadox® (Carbadox, 50 g/ton). Overall (d 0 to 28 after weaning), pigs fed diets containing Denagard/CTC or Neo-Terramycin® had greater ADG and ADFI ($P<0.05$) than did pigs fed all other diets, and had improved F/G ($P<0.05$), compared with that of pigs fed the control diet. Also, pigs fed diets containing Mecadox® had improved ADG and F/G ($P<0.05$) compared with those of pigs fed the control diet. The addition of feed-grade antibiotics in swine diets resulted in improved growth performance, and pigs fed Denagard/CTC or Neo-Terramycin® had the greatest improvement in growth performance.

(Key Words: Nursery Pigs, Antibiotics, Growth, Pigs.)

Introduction

The use of feed-grade antibiotics in nursery-pig diets has long been recognized as a method to improve growth performance and health. For many years, the research facility at the Kansas State University Swine Teaching and Research Center has almost exclusively used Mecadox® (Carbadox, 50 g/ton) in all nursery pig diets. But data published in the Swine Day 2003 report indicated that pigs fed Mecadox® in a commercial research facility did not have improved growth performance, compared with performance of those fed a diet without feed-grade antibiotics. This commercial research facility had almost exclusively used Mecadox® in nursery diets for several years. Therefore, we conducted this trial to evaluate the effectiveness of our current feed-medication protocol and compare the effects of different antibiotic feed additives on nursery-pig growth performance.

Procedures

A total of 168 weanling pigs (initially 13.8 lb and 21 ± 3 d of age, PIC L326 x C22) were blocked by initial weight and randomly allotted to one of four dietary treatments. There were six pigs per pen and seven pens per treatment. All pigs were fed treatment diets for 28 d after weaning. There were four experimental diets: a control diet with no added feed grade antibiotics, or the control diet with added Denagard/CTC (35 g/ton Denagard™, 400 g/ton Chlortetracycline); Neo-Terramycin® (140 g/ton Neomycin Sulfate, 140

[1]Food Animal Health and Management Center.

g/ton Oxytetracycline HCl); or Mecadox® (Carbadox, 50 g/ton).

Dietary treatments were fed in meal form (Table 1). Phase 1 (d 0 to 14 after weaning) diets were formulated to contain 1.41% true-ileal-digestible (TID) lysine, 0.90% Ca, and 0.52% available phosphorus. Phase 2 (d 14 to 28 post weaning) diets were formulated to contain 1.31% TID lysine, 0.85% Ca, and 0.42% available phosphorus. The trial was conducted in an environmentally controlled nursery facility at the Kansas State University Swine Teaching and Research Center. Each pen was 5 × 5 ft and contained one self-feeder and one nipple waterer to provide ad libitum access to feed and water. Average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (F/G) were determined by weighing pigs and feeders on d 7, 14, and 28 after weaning. Data were analyzed as a randomized complete-block design with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS.

Results and Discussion

From d 0 to 14, pigs fed diets containing Denagard/CTC or Neo-Terramycin had greater ADG ($P<0.05$) than did pigs fed the non-antibiotic control diet (Table 2). Pigs fed diets containing Denagard/CTC had greater ADFI ($P<0.05$), compared with that of pigs fed Mecadox®. Pigs fed diets containing Neo-Terramycin had improved F/G ($P<0.05$), compared with that of pigs fed the non-antibiotic control diet.

From d 14 to 28, pigs fed the diet containing Neo-Terramycin had the greatest ADG ($P<0.05$), compared with that of pigs fed all other diets and had greater ADFI ($P<0.05$) than did pigs fed diets containing Mecadox® or the non-antibiotic control diet. Also, pigs fed diets containing Neo-Terramycin had improved F/G ($P<0.05$), compared with that of pigs fed diets containing Denagard/CTC or the non-antibiotic control diet.

For the overall treatment period (d 0 to 28 after weaning), pigs fed diets containing Denagard/CTC or Neo-Terramycin® had greater ADG and ADFI ($P<0.05$) than did pigs fed all other diets and had improved F/G compared with that of pigs fed the non-antibiotic control diet. Pigs fed diets containing Mecadox® were intermediate in performance, and had greater ADG ($P<0.05$) and improved F/G ($P<0.05$), compared with that of pigs fed the non-antibiotic control diet. Numerically, pigs fed Neo-Terramycin had the greatest ADG and best F/G, compared with those of pigs fed all other diets.

The addition of antibiotics to swine diets resulted in improved growth performance, with pigs fed Denagard/CTC or Neo-Terramycin® having the greatest improvement in growth performance. On the basis of results, producers should periodically evaluate the effectiveness of their feed-additive protocol.

Table 1. Diet Composition (As-fed Basis)

Ingredient, %	Phase 1[a]	Phase 2[b]
Corn	48.14	60.00
Soybean meal, 46.5% CP	28.99	35.00
Spray dried whey	15.00	---
Select menhaden fish meal	3.75	---
Monocalcium phosphate, 21% P	1.15	1.60
Limestone	0.70	1.10
Salt	0.30	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-Threonine	0.12	0.13
Lysine HCl	0.30	0.30
DL-Methionine	0.15	0.13
Test ingredient[c]	1.00	1.00
TOTAL	100.00	100.00
Calculated Analysis		
Total lysine, %	1.55	1.45
True Digestible Amino Acids		
Lysine	1.41	1.31
Isoleucine:lysine ratio, %	61	63
Leucine:lysine ratio, %	120	129
Methionine:lysine ratio, %	33	33
Met & cys:lysine ratio, %	57	57
Threonine:lysine ratio, %	65	63
Tryptophan:lysine ratio, %	17	18
Valine:lysine ratio, %	68	69
ME, kcal/lb	1,477	1,479
CP, %	21.7	21.4
Ca, %	0.90	0.85
P, %	0.80	0.75
Available P, %	0.52	0.42

[a]Phase 1 fed from d 0 to 14 post weaning.
[b]Phase 2 fed from d 14 to 28 post weaning.
[c]Corn starch; Denagard/CTC (35 g/ton Denagard™, 400 g/ton Chlortetracycline); Neo-Terramycin® (140 g/ton Neomycin Sulfate, 140 g/ton Oxytetracycline HCl); or Mecadox® (Carbadox 50 g/ton).

Table 2. Effects of Different Feed-grade Antibiotics on Growth Performance of Weanling Pigs[a]

	Dietary Treatment[f]				
Item	Control	Denagard/CTC	Neo-Terramycin	Mecadox®	SE
Day 0 to 14					
ADG, lb	0.39[c]	0.48[b]	0.48[b]	0.42[bc]	0.03
ADFI, lb	0.47[bc]	0.52[b]	0.50[bc]	0.46[c]	0.02
F/G	1.27[b]	1.11[bc]	1.04[c]	1.10[bc]	0.07
Day 14 to 28					
ADG, lb	1.06[e]	1.20[c]	1.28[b]	1.15[d]	0.02
ADFI, lb	1.43[c]	1.56[b]	1.58[b]	1.48[c]	0.04
F/G	1.35[b]	1.30[c]	1.24[d]	1.28[cd]	0.02
Day 0 to 28					
ADG, lb	0.72[d]	0.84[b]	0.88[b]	0.79[c]	0.02
ADFI, lb	0.94[c]	1.04[b]	1.04[b]	0.97[c]	0.03
F/G	1.32[b]	1.24[c]	1.18[c]	1.23[c]	0.03

[a]A total of 168 pigs with initial average BW of 13.8 lb.

[b,c,d,e]Means in the same row with different superscripts differ (P<0.05).

[f]Corn starch; Denagard/CTC (35 g/ton Denagard™, 400 g/ton Chlortetracycline); Neo-Terramycin® (140 g/ton Neomycin Sulfate, 140 g/ton Oxytetracycline HCl); or Mecadox® (Carbadox 50 g/ton).

THE EFFECT OF A PROBIOTIC, KE-01, AND NEOTERRAMYCIN ON NURSERY PIG GROWTH PERFORMANCE[1]

N. Z. Frantz, J. L. Nelssen, J. M. DeRouchey, R. D. Goodband, M. D. Tokach, and S. S. Dritz[2]

Summary

A 35-d growth study with a total of 168 weanling pigs (21 ± 2 d of age) was conducted to determine the effects of feeding a probiotic, (KE-01) and an antibiotic, Neoterramycin (neomycin 140 g/ton, oxytetracycline 140 g/ton), on nursery pig performance. Experimental treatments were arranged in a 2 × 2 factorial with main effects of antibiotic (none or neomycin 140g/ton and oxytetracycline 140g/ton) or probiotic (none or KE-01, 0.35%). KE-01 is a probiotic containing a novel strain of lactobacillus casei. A KE-01 by Neoterramycin interaction was observed for ADFI (P<0.05) from d 14 to 35, but no other interactions were detected. From d 0 to 14, pigs fed diets containing Neoterramycin had improved (P<0.01) ADG, ADFI, and F/G compared with those of pigs fed diets without Neoterramycin. Pigs fed diets containing KE-01 had similar growth performance to that of pigs fed diets without KE-01. From d 14 to 35, pigs fed diets containing Neoterramycin had increased ADG compared with that of pigs fed diets without Neoterramycin. The ADG of pigs fed diets containing KE-01 did not differ from that of pigs fed diets without KE-01. There was a tendency for pigs fed KE-01 to consume less feed, whereas pigs fed Neoterramycin ate more (KE-01 × Neoterramycin interaction, P<0.05). Pigs fed diets containing KE-01 tended to have improved F/G (P<0.07), compared with that of pigs fed diets without KE-01. Overall, d 0 to 35, pigs fed diets containing Neoterramycin had increased ADG and ADFI (P<0.01), compared with those of pigs fed diets without Neoterramycin. In addition, pigs fed diets containing KE-01 had similar ADG and ADFI to those of pigs fed diets without KE-01. Pigs fed diets containing KE-01 had improved F/G (P<0.03), compared with that of pigs fed diets without KE-01. In summary, the probiotic, KE-01, did not significantly increase ADG or ADFI, but did improve F/G because it slightly lowered feed intakes. Neoterramycin improved ADG, ADFI, and F/G, compared with those of diets without Neoterramycin in this study.

(Key Words: Antibiotics, Pigs, Probiotic, Weanling Pigs.)

Introduction

Previous experiments at Kansas State University have demonstrated that adding a feed-grade antimicrobial (Neoterramycin, Mecadox, or Denagard CTC) to the nursery diet consistently increases ADG and improves F/G. KE-01 is a novel strain of Lactobacillus casei. In an initial field trial, feeding KE-01 improved weight gain and bacterial detach-

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[2]Food Animal Health and Management Center.

ment. An oral dose of KE-01 also has been shown to reduce sulfide and ammonia compounds in feces in pigs. Initial field trials with KE-01 look promising, but growth responses must be verified in controlled experiments. This study was conducted to evaluate the effectiveness of the probiotic KE-01 to enhance nursery pig performance.

Procedures

A total of 168 weaned pigs (PIC, initially 13.7 lb and 21 ± 2 d of age) were blocked by weight in a 35 day growth study. Pigs were randomly allotted to one of four dietary treatments in a randomized complete block design. Each pen contained six pigs per pen, with seven replicates (pens) per treatment. Pigs were housed at the Kansas State Swine Research and Teaching Center. All pens (4 × 5 ft) contained one stainless steel self-feeder and one nipple waterer to allow ad libitum access to feed and water.

Pigs were fed one of four experimental diets, arranged in a 2 × 2 factorial consisting of antibiotic (none or neomycin, 140 g/ton and oxytetracycline, 140 g/ton) or probiotic (none or KE-01, 0.35%). Experimental diets were based on corn-soybean meal and were fed in meal form for the 35-day trial. The phase 1 diet (1.55% lysine) was fed from d 0 to14, and phase 2 diet (1.45% lysine) was fed from d 14 to 35 post-weaning (Table 1). Diets did not contain growth-promoting amounts of zinc oxide. Also, no water antimicrobials were administered throughout the trial. Pigs were weighed, and feed disappearance was measured on d 0, 7, 14, 21, 28, and 35 to determine ADG, ADFI, and feed efficiency (F/G). Data were analyzed as a randomized complete-block design with pen as the experimental unit by using the Mixed procedure of SAS.

Results and Discussion

From d 0 to 14, no interactions were observed ($P>0.53$); therefore, the treatment main effects are presented in Table 2 and the interactive means are shown in Table 3. Pigs fed diets containing Neoterramycin had improved ADG, ADFI, and F/G ($P<0.01$), compared with those of pigs fed diets without Neoterramycin. Pigs fed diets with KE-01 had similar ADG, ADFI, and F/G ($P>0.12$) to those of pigs fed diets without KE-01.

From d 14 to 35, a KE-01 by Neoterramycin interaction was detected for ADFI ($P<0.05$). This was because of a slight reduction in ADFI in pigs fed KE-01; Neoterramycin increased ADFI. Pigs fed diets containing Neoterramycin had increased ADG and ADFI ($P<0.01$) compared with those of pigs fed diets without Neoterramycin. Adding KE-01 to the diet had no effect on ADG and ADFI ($P>0.59$), but tended ($P<0.07$) to improve F/G.

For the overall treatment period (d 0 to 35), a tendency for an interaction was observed on ADFI ($P<0.08$). Pigs fed diets containing Neoterramycin had greater ADG and ADFI ($P<0.01$), compared with those of pigs fed diets without Neoterramycin. Pigs fed diets containing KE-01 had similar ADG and ADFI ($P>0.45$) to those of pigs fed diets without KE-01. But pigs fed diets containing KE-01 had improved F/G ($P<0.03$), compared with that of pigs fed diets without KE-01.

In agreement with many previous trials, this study found that feeding diets containing an antibiotic such as Neoterramycin to nursery pigs resulted in improved growth performance. The probiotic, KE-01, did not improve ADG or ADFI, but slightly improved F/G.

Table 1. Diet Composition (As-fed Basis)[a]

Ingredient, %	Phase 1[b]	Phase 2[c]
Corn	48.13	59.99
Soybean meal, 46.5% CP	29.00	35.01
Spray-dried whey	15.00	-
Select menhaden fish meal	3.75	-
Test ingredient or starch[d]	1.00	1.00
Monocalcium phosphate, 21% P	1.15	1.60
Limestone	0.70	1.10
Salt	0.30	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-Lysine HCl	0.30	0.30
DL-Methionine	0.15	0.13
L-Threonine	0.13	0.13
TOTAL	100.00	100.00
Calculated Analysis		
Lysine, %	1.55	1.45
Isoleucine:lysine ratio, %	61	61
Leucine:lysine ratio, %	120	120
Methionine:lysine ratio, %	33	32
Met & Cys:lysine ratio, %	57	58
Threonine:lysine ratio, %	65	65
Tryptophan:lysine ratio, %	17	18
Valine:lysine ratio, %	68	71
ME, kcal/lb	1,473	1,478
CP, %	21.7	21.4
Ca, %	0.90	0.85
P, %	0.80	0.75
Lysine:calorie ratio, g/mcal	4.78	4.45

[a]All diets fed in meal form.
[b]Fed from d 0 to 14 post-weaning.
[c]Fed from d 14 to 35 post-weaning.
[d]Neoterramycin (neomycin 140 g/ton and oxytetracycline 140 g/ton), KE-01 (Lactobacillus casei, 0.30% and 0.35%, phase 1 and 2, respectively) replaced corn starch to provide additional dietary treatments.

Table 2. Main Effects of KE-01 and In-feed Neomycin/Oxytetracycline on Growth Performance of Nursery Pigs[a]

	KE-01[c]		Neoterramycin			P - value		
Item	0	0.35%[d]	0	140 g/ton	SE	KE-01	Neoterramycin	KE-1 * Neoterramycin
Pens[b]	14	14	14	14				
Day 0 to 14								
ADG, lb	0.63	0.62	0.57	0.68	0.024	0.77	0.01	0.56
ADFI, lb	0.73	0.70	0.67	0.75	0.027	0.38	0.01	0.53
F/G	1.15	1.12	1.17	1.11	0.018	0.12	0.01	0.98
Day 14 to 35								
ADG, lb	1.35	1.35	1.29	1.41	0.024	0.77	0.01	0.11
ADFI, lb	1.91	1.89	1.80	1.99	0.034	0.59	0.01	0.05
F/G	1.41	1.39	1.40	1.41	0.010	0.07	0.54	0.36
Day 0 to 35								
ADG, lb	1.06	1.06	1.00	1.12	0.020	0.94	0.01	0.15
ADFI, lb	1.43	1.41	1.35	1.50	0.027	0.45	0.01	0.08
F/G	1.35	1.33	1.35	1.33	0.009	0.03	0.15	0.39
Final Weight, lb	50.81	50.9	48.74	52.97	0.709	0.91	0.01	0.15

[a]Diets fed in meal form, with phase 1 fed from d 0 to 14 and phase 2 fed from d 14 to 35.
[b]Comparison of two diets with, versus two without, KE-01 and two with, versus two without, Neoterramycin.
[c]A novel Lactobacillus casei strain.
[d]KE-01 fed at 0.30% phase 1 and 0.35% phase 2, respectively.

Table 3. Effect of Probiotic, KE-01, and In-feed Neomycin/Oxytetracyline on Growth Performance of Weanling Pigs[a]

						P-value			
Item	Control	KE-01[bc]	Neoterramycin	KE-01 and Neoterramycin	SED	Treatment	KE-01 *Neoterramycin	Med vs. non-Med	KE-01 vs. No KE-01
Day 0 to 14									
ADG, lb	0.57[d]	0.58[d]	0.69[e]	0.67[e]	0.034	0.01	0.56	0.01	0.77
ADFI, lb	0.68[d]	0.67[d]	0.77[e]	0.73[de]	0.038	0.04	0.53	0.01	0.38
F/G	1.19[d]	1.16[de]	1.12[ef]	1.09[f]	0.025	0.01	0.98	0.01	0.12
Day 14 to 35									
ADG, lb	1.26[d]	1.31[d]	1.43[e]	1.40[e]	0.034	0.01	0.11	0.01	0.77
ADFI, lb	1.78[d]	1.83[d]	2.04[e]	1.95[e]	0.048	0.01	0.05	0.01	0.59
F/G	1.41	1.40	1.42	1.39	0.02	0.19	0.36	0.54	0.07
Day 0 to 35									
ADG, lb	0.99[d]	1.02[d]	1.14[e]	1.11[e]	0.029	0.01	0.15	0.01	0.95
ADFI, lb	1.34[d]	1.37[d]	1.53[e]	1.46[e]	0.038	0.01	0.08	0.01	0.45
F/G	1.35[d]	1.34[de]	1.35[d]	1.32[e]	0.013	0.07	0.39	0.15	0.03
Final weight, lb	48.16[d]	49.33[d]	53.46[e]	52.48[e]	1.00	0.01	0.15	0.01	0.91

[a]Diets fed in meal form, with phase 1 fed from d 0 to 14 and phase 2 fed from d 14 to 35.
[b]A novel Lactobacillus casei strain.
[c]KE-01 fed at 0.30% phase 1 and 0.35% phase 2, respectively.
[d,e,f]Means having different superscript letters differ P<0.05.

EFFECT OF CARNICHROME® ON GROWTH PERFORMANCE OF WEANLING PIGS IN A COMMERCIAL ENVIRONMENT[1]

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Summary

A 43-day growth study with a total of 384 weanling pigs (14 ± 2 d of age) was conducted to evaluate the effects of Carnichrome®, a combination of L-carnitine and chromium picolinate, on growth performance of weanling pigs. Secondary objectives were to compare pigs fed diets with or without a feed-grade medication, evaluate any interactive effects between Carnichrome and medication, and identify any carryover effect once medication was withdrawn from the diet. Experimental diets were arranged in a 2 × 3 factorial to compare the main effects of medication (none or Denagard/CTC, 35/400 g/ton) and Carnichrome (none, 25, and 100, or 50 and 100 ppm, respectively, of L-carnitine and chromium picolinate). No interactions between Carnichrome and Denagard/CTC were detected (P>0.17). Pigs fed Denagard/CTC had improved ADG (P<0.01), and F/G (P<0.02) from d 0 to 10, 10 to 29, 0 to 29, and overall (d 0 to 43) compared with those of pigs fed diets without Denagard/CTC. In addition, pigs fed diets containing Denagard/CTC tended to have increased ADFI (P<0.08) from d 0 to 10, and significantly increased ADFI (P<0.01) from d 10 to 29, 0 to 29, and overall (d 0 to 43). No differences in ADG, ADFI, and F/G were seen for pigs fed diets containing either rate of Carnichrome, compared with those of pigs fed the negative control diet. For the period d 29 to 43, when pigs were fed a common phase 3 diet, there were no differences in ADG, ADFI, or F/G between treatments (P>0.14), and no carryover effect of medication resulted. Pigs fed nursery diets containing Carnichrome did not have enhanced growth performance, but pigs fed diets containing Denagard/CTC had improved ADG, ADFI, and F/G compared with those of pigs fed diets without Denagard/CTC.

(Key Words: Antibiotics, L-carnitine, Chromium, Pigs, Weanling Pigs.)

Introduction

L-carnitine is a vitamin-like compound that aids in the movement of fatty acids across the mitochondrial membrane to be broken down for energy, and may be required to aid in the utilization of fat sources, along with having other functions. Chromium, a trace mineral that is a component of glucose-tolerance factor, is important in carbohydrate, fat, and protein metabolism through its potentiating action on insulin, and may reduce backfat by limiting the response to insulin from a meal.

[1]The authors thank Lonza, Inc. for partial financial support and providing the Carnichrome® used in this study. We also thank Eichman Brothers for their cooperation and help, and use of their facilities.
[2]Food Animal Health and Management Center
[3]Lonza, Inc. Fair Lawn, NJ.

Research involving L-carnitine and chromium has suggested reduction in body weight loss in sows and reduced backfat in finishing pigs. Previous research from Kansas State University and Oklahoma State University has shown that supplementing nursery pig diets with L-carnitine can improve ADG and feed efficiency. But the combination of L-carnitine and chromium has not been evaluated in nursery pigs. Carnichrome® is a combination product of L-carnitine and chromium picolinate. Therefore, the objectives were to determine whether a combination of L-carnitine and chromium picolinate, as Carnichrome, can influence weanling pig performance and to determine if interactive effects of Carnichrome and medication exist.

Procedures

A total of 384 weaned pigs (initially 12.1 lb and 14 ± 2 d of age) were blocked by weight in a 43-day growth study. They were randomly allotted to one of six dietary treatments in a randomized complete-block design. Each pen contained eight pigs per pen, with eight replicates (pens) per treatment. Pigs were housed at a commercial farm in northeastern Kansas in an environmentally controlled nursery. All pens (4 × 6 ft) contained one stainless steel self-feeder and two nipple waterers to allow ad libitum access to feed and water.

Pigs were fed one of six experimental diets arranged in a 2 × 3 factorial consisting of antibiotic (with or without) and two concentrations of Carnichrome. Diets were: no antibiotic or Carnichrome (negative control); Carnichrome (25 ppm L-carnitine and 100 ppb chromium picolinate); Carnichrome (50 ppm L-carnitine and 200 ppb chromium picolinate); Denagard/CTC (35 g/ton Denagard™, 400 g/ton Chlortetracycline) (positive control); Denagard/CTC plus Carnichrome (25 ppm L-carnitine and 100 ppb chromium picolinate); or Denagard/CTC plus Carnichrome (50 ppm L-carnitine and 200 ppb chromium picolinate).

Experimental diets were based on corn-soybean meal and were fed in meal form for 29 days after weaning; a common diet was fed from d 29 to 43. The SEW diets (1.7% lysine) were fed on a feed budget of one pound per pig, transition diets (1.6% lysine) were fed after the SEW diet until d 10, and phase 2 diets (1.51% lysine) were fed from d 10 to 29 after weaning (Table 1). Diets contained growth-promoting amounts of zinc oxide. A common phase 3 diet was fed from d 29 to 43 to evaluate potential carryover effects. Pigs were weighed, and feed disappearance was measured, on d 0, 10, 17, 24, 29, and 43 to determine ADG, ADFI, and F/G. Data were analyzed as a randomized complete-block design, with pen as the experimental unit, by using the Mixed procedure of SAS.

Results and Discussion

No Denagard/CTC by Carnichrome interactions were detected for ADG, ADFI, or F/G ($P>0.17$); therefore, the treatment main effects are presented in Table 2. The individual treatment means are also shown in Table 3.

From d 0 to 10, pigs fed diets containing Denagard/CTC had improved ADG and F/G ($P<0.01$), compared with those of pigs fed diets without Denagard/CTC. In addition, pigs fed diets containing Denagard/CTC tended to have increased ADFI ($P<0.08$), compared with that of pigs fed diets without Denagard/CTC. Pigs fed diets with either rate of Carnichrome had ADG, ADFI, and F/G ($P>0.47$) similar to those of pigs fed diets without Carnichrome.

From d 10 to 29, pigs fed diets containing Denagard/CTC had improved

ADG, ADFI, and F/G (P<0.01), compared with those of pigs fed diets without Denagard/CTC. Adding Carnichrome to the diet had no effect on ADG, ADFI, and F/G (P>0.41).

For the overall treatment period (d 0 to 29), pigs fed diets containing Denagard/CTC had greater ADG, ADFI, and improved F/G (P<0.01), compared with those of pigs fed diets without Denagard/CTC. Pigs fed diets containing either rate of Carnichrome had ADG, ADFI, and F/G (P>0.36) similar to those of pigs fed diets without Carnichrome.

From d 29 to 43, when pigs were fed a common diet, ADG, ADFI, and F/G were similar for all treatment groups (P>0.14).

For the overall trial period (d 0 to 43), pigs fed diets containing Denagard/CTC had greater ADG (P<0.01), ADFI (P<0.01), and F/G (P<0.02), compared with those of pigs fed diets without Denagard/CTC. Pigs fed diets containing either rate of Carnichrome had ADG, ADFI, and F/G (P>0.31) similar to those of pigs fed diets without Carnichrome.

In agreement with many previous trials, results showed that feeding diets containing an antibiotic such as Denagard/CTC to nursery pigs improved growth performance, but supplementation with either rate of Carnichrome did not improve ADG, ADFI, or F/G in this study. There also were no interactive effects of combining Carnichrome with Denagard/CTC.

Table 1. Diet Composition (As-fed Basis)[a]

Ingredient, %	SEW[b]	Transition[b]	Phase 2[c]	Phase 3[d]
Corn	40.25	41.20	50.75	-
Milo	-	-	-	58.40
Spray dried whey	25.00	25.00	10.00	-
Soybean meal, 46.5% CP	12.10	21.55	27.70	34.95
Spray-dried plasma	6.70	2.50	-	-
Select menhaden fish meal	6.00	6.00	4.50	-
Spray-dried blood meal	1.65	-	-	-
Lactose	5.00	-	-	-
Choice white grease	-	-	3.00	3.00
Test ingredient or starch[e]	1.00	1.00	1.00	-
Monocalcium phosphate, 21% P	0.50	0.75	1.00	1.00
Limestone	0.40	0.50	0.55	0.95
Zinc oxide	0.38	0.38	0.25	-
Salt	0.25	0.30	0.30	0.35
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
Lysine HCl	0.15	0.20	0.30	0.30
DL-Methionine	0.15	0.13	0.15	0.10
L-Threonine	0.08	0.08	0.10	0.07
TOTAL	100.00	100.00	100.00	100.00
Calculated Values				
Lysine, %	1.70	1.60	1.51	1.42
Isoleucine:lysine ratio, %	51	60	61	68
Methionine:lysine ratio, %	30	32	34	30
Met & Cys:lysine ratio, %	56	57	58	56
Threonine:lysine ratio, %	66	66	64	63
Tryptophan:lysine ratio, %	18	18	17	20
Valine:lysine ratio, %	73	69	68	75
ME, kcal/lb	1,489	1,476	1,545	1,538
CP, %	22.6	22.3	21.2	21.6
Ca, %	0.81	0.92	0.81	0.68
P, %	0.78	0.83	0.75	0.62
Lysine:calorie ratio, g/mcal	5.18	4.92	4.43	4.19

[a]All diets fed in meal form.
[b]Pigs were fed one pound of SEW diet and then transition diet until d 10 postweaning.
[c]Fed from d 10 to 29 after weaning.
[d]Fed from d 29 to 43 after weaning.
[e]Denagard/CTC (Denagard™ 35 g/ton; Chlortetracycline 400 g/ton), Carnichrome (25 ppm L-carnitine, 100 ppb chromium picolinate), or Carnichrome (50 ppm L-carnitine, 200 ppb chromium picolinate) replaced corn starch to provide additional dietary treatments.

Table 2. Main Effects of Carnichrome and Denagard/CTC on Growth Performance of Nursery Pigs[a]

	Denagard/CTC[b]		Carnichrome[c]				Carnichrome		P-value		
Item	0	35g, 400g/ton	0	0.025%	0.05%	SE	Linear	Quadratic	Carnichrome	Denagard/ CTC	Denagard/CTC *Carnichrome
Replicates	24	24	16	16	16						
Day 0 to 10											
ADG, lb	0.40	0.47	0.45	0.42	0.43	0.034	0.50	0.31	0.47	0.01	0.20
ADFI, lb	0.48	0.51	0.50	0.48	0.50	0.035	0.89	0.34	0.62	0.08	0.48
F/G	1.19	1.10	1.14	1.15	1.16	0.037	0.48	0.97	0.77	0.01	0.20
Day 10 to 29											
ADG, lb	1.06	1.14	1.12	1.09	1.10	0.031	0.50	0.26	0.41	0.01	0.23
ADFI, lb	1.47	1.56	1.52	1.50	1.52	0.043	0.94	0.34	0.63	0.01	0.24
F/G	1.41	1.38	1.38	1.40	1.40	0.021	0.37	0.65	0.60	0.01	0.31
Day 0 to 29											
ADG, lb	0.83	0.91	0.89	0.86	0.87	0.028	0.47	0.22	0.36	0.01	0.20
ADFI, lb	1.13	1.20	1.17	1.15	1.17	0.037	0.95	0.31	0.59	0.01	0.23
F/G	1.38	1.35	1.35	1.37	1.37	0.019	0.25	0.59	0.43	0.01	0.54
Day 29 to 43											
ADG, lb	1.32	1.33	1.33	1.31	1.34	0.046	0.93	0.44	0.74	0.74	0.92
ADFI, lb	2.09	2.14	2.12	2.09	2.14	0.065	0.76	0.26	0.51	0.15	0.19
F/G	1.58	1.61	1.60	1.60	1.60	0.036	0.99	0.92	0.99	0.14	0.18
Day 0 to 43											
ADG, lb	0.99	1.05	1.03	1.00	1.02	0.023	0.67	0.15	0.31	0.01	0.42
ADFI, lb	1.44	1.50	1.48	1.45	1.49	0.036	0.71	0.20	0.40	0.01	0.32
F/G	1.43	1.41	1.41	1.43	1.43	0.017	0.25	0.71	0.47	0.02	0.17

[a]A total of 384 pigs approximately 12.1 lbs and 14 ± 2 d of age on a commercial farm in northeastern Kansas.
[b]Inclusion rate of Denagard (35 g/ton) CTC (400 g/ton).
[c]Contains L-carnitine (25, 50 ppm) and Chromium picolinate (100, 200 ppb), respectively.

Table 3. Effects of Carnichrome and Denagard/CTC on Growth Performance of Weanling Pigs in a Commercial Environment[a]

Item	Control	Carnichrome[b] (25, 100)	Carnichrome[b] (50, 200)	Dena/ CTC[c]	Dena/CTC* Carnichrome (25, 100)	Dena/CTC* Carnichrome (50, 200)	SED	P-value Treatment	P-value Med vs. non-Med
Day 0 to 10									
ADG, lb	0.40[d]	0.41[d]	0.41[d]	0.51[e]	0.43[d]	0.46[de]	0.029	0.02	0.01
ADFI, lb	0.47	0.48	0.48	0.54	0.49	0.52	0.030	0.35	0.08
F/G	1.20[d]	1.17[def]	1.19[de]	1.07[g]	1.13[efg]	1.12[fg]	0.027	0.01	0.01
Day 10 to 29									
ADG, lb	1.07[de]	1.06[de]	1.04[d]	1.16[f]	1.11[ef]	1.16[f]	0.046	0.01	0.01
ADFI, lb	1.46[d]	1.48[d]	1.47[d]	1.59[e]	1.51[de]	1.58[e]	0.067	0.01	0.01
F/G	1.39[de]	1.41[de]	1.42[d]	1.38[e]	1.38[e]	1.37[e]	0.015	0.12	0.02
Day 0 to 29									
ADG, lb	0.83[d]	0.84[d]	0.82[d]	0.94[f]	0.88[de]	0.92[ef]	0.038	0.01	0.01
ADFI, lb	1.11[d]	1.14[d]	1.13[d]	1.22[e]	1.16[de]	1.22[e]	0.052	0.02	0.01
F/G	1.37[def]	1.38[de]	1.40[d]	1.34[f]	1.35[def]	1.34[f]	0.013	0.02	0.01
Day 29 to 43									
ADG, lb	1.32	1.30	1.34	1.34	1.32	1.33	0.040	0.97	0.74
ADFI, lb	2.06[de]	2.05[d]	2.15[de]	2.18[e]	2.12[de]	2.12[de]	0.069	0.24	0.15
F/G	1.56[e]	1.58[de]	1.61[de]	1.64[d]	1.61[de]	1.59[de]	0.039	0.34	0.14
Day 0 to 43									
ADG, lb	0.99[d]	0.99[d]	0.99[d]	1.07[e]	1.02[de]	1.05[e]	0.031	0.01	0.01
ADFI, lb	1.42[d]	1.43[d]	1.46[de]	1.53[e]	1.47[de]	1.51[e]	0.054	0.02	0.01
F/G	1.42[e]	1.43[de]	1.45[d]	1.41[e]	1.42[e]	1.40[e]	0.015	0.07	0.02

[a]A total of 384 pigs approxiatmetly 12.1 lbs and 14 ± 2 d of age in a commercial unit in Northeast Kansas.
[b]Contains L-carnitine (50 ppm) and Chromium (200 ppb).
[c]Inclusion rate of Denagard (35 g/ton) CTC (400 g/ton).
[d,e,f,g]Values with different superscripts differ (P< 0.05).

THE EFFECT OF REPLACING SPECIALTY PROTEIN SOURCES WITH SYNTHETIC AMINO ACIDS IN PHASE 2 NURSERY-PIG DIETS[1]

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Summary

A 28-d growth study with a total of 1,500 pigs (7 d after weaning and 14.5 lb initial BW) was conducted to compare differences in pig performance when fed either fish meal, poultry meal, or synthetic amino acids in a phase 2 nursery-pig diet. In addition, pigs were fed either a negative-control diet (predominately soybean meal without specialty protein sources) or a positive-control diet containing both blood meal and fish meal. Spray-dried whey was added to all diets at 10% and fat was added at 3%. All diets were formulated to meet minimum amino acid ratios. From d 7 to 17, feeding pigs the positive-control diet or the diet high in synthetic amino acids resulted in improved ADG and F/G ($P<0.01$), compared with those of pigs fed the negative-control, fish-meal, or poultry-meal diets. Pigs fed the positive-control diet or the synthetic amino acid diet were heavier at d 17 ($P<0.01$) than were pigs fed the negative control or diets containing fish or poultry meal. There was no treatment effect on ADFI ($P>0.34$). When all pigs were fed a common diet from d 17 to 35, similar ADG and F/G were observed between all dietary treatments ($P>0.17$); but pigs fed the positive-control diet had increased ADFI ($P<0.01$) compared with that of the negative control or of diets containing fish meal, poultry meal, or synthetic amino acids. For the overall treatment period (d 7 to 35), pigs fed the positive-control diet had greater ADG ($P<0.01$) and were heavier ($P<0.01$) than were pigs fed the negative-control diet or fed diets containing fish meal or poultry meal; the performance pigs fed the diet containing high concentrations of synthetic amino acids was intermediate. Pigs fed the positive-control diet also had increased ADFI ($P<0.01$), compared with that of pigs fed the other dietary treatments. Pigs fed the diet containing high concentrations of synthetic amino acids or the positive-control diet tended to have improved F/G ($P<0.07$), compared with that of pigs fed the other dietary treatments. In summary, synthetic amino acids were an effective replacement for specialty protein sources, such as fish meal or poultry meal, in the phase 2 diet.

(Key Words: Pigs, Protein Sources, Synthetic Amino Acids, Weanling Pigs.)

Introduction

Previous experiments at Kansas State University have demonstrated that adding synthetic L-lysine HCl in excess of the normal 3 lb per ton inclusion requires the addition of other essential amino acids to the diet. The use of high concentrations of synthetic amino acids in nursery diets may provide an effective alternative to specialty protein sources when the specialty ingredients are expensive. Specialty protein sources, such as fish meal or

[1]The authors thank Anijomoto-Heartland Lysine, Chicago, IL, for partial financial support and for providing the amino acids used in this study.
[2]Food Animal Health and Management Center.

blood meal, are used in nursery diets to improve feed intake and average daily gain. There has recently been some question as to whether the benefit in increased feed intake is due to the protein source itself or because adding the protein source reduces the amount of soybean meal in the diet. Poultry meal is another amino acid source that is currently being used to reduce cost in nursery diets. This study was conducted to evaluate the effectiveness of replacing protein sources, such as fish meal or poultry meal, with synthetic amino acids to improve nursery-pig performance.

Procedures

A total of 1,500 weaned pigs (PIC, initially 14.5 lb and 7 d after weaning) were blocked by weight in a 28-day growth study. Pigs were randomly allotted to one of five dietary treatments in a randomized complete-block design. Each pen contained 25 pigs per pen, and two pens shared a common fence-line feeder, resulting in six replicates (pens) per treatment, with two pens as the experimental unit. Pigs were housed at a commercial facility in southwestern Minnesota.

Pigs were fed one of five experimental diets consisting of a negative-control diet based on corn-soybean meal as the sole protein source, or a positive-control diet that contained both fish meal and blood meal. Either fish meal, poultry meal, or added synthetic amino acids (L-lysine, L-threonine, DL-methionine, Isoleucine, Valine, and Tryptophan) replaced the amino acids provided by the blood meal and fish meal in the positive-control diet. The objective of testing the diet having the increased synthetic amino acid content was to see if synthetic amino acid, at rates in excess of that currently used in diets today, could replace the specialty protein sources.

Experimental diets were based on corn-soybean meal with 10% added whey and 3% added fat. The experimental diets (1.55% total lysine) were fed from d 7 to 17 after weaning (Table 1), and a common diet was fed from d 17 to d 35. Diets did not contain growth-promoting amounts of zinc oxide. Pigs and feeders were weighed on d 7, 17, and 35 after weaning to determine ADG, ADFI, and F/G. Data were analyzed as a randomized complete-block design, with the experimental unit as two pens sharing a common fence-line feeder, by using the Mixed procedure of SAS.

Results and Discussion

From d 7 to 17, feeding pigs the positive-control diet or a diet high in synthetic amino acids resulted in improved ($P<0.01$) ADG and F/G, and resulted in heavier ($P<0.01$) weights compared with those of pigs fed the negative-control, fish-meal, or poultry-meal diets (Table 2). There was no treatment effect on ADFI ($P>0.34$).

When all pigs were fed a common diet from d 17 to 35, similar ADG and F/G were observed between all dietary treatments ($P>0.17$); but pigs fed the positive-control diet from d 7 to 17 had increased ADFI ($P<0.01$) from d 17 to 35, compared with that of pigs fed the negative control or diets containing fish meal or poultry meal, or a diet high in synthetic amino acids.

For the overall treatment period (d 7 to 35), pigs fed the positive-control diet from d 0 to 7 had greater ADG ($P<0.01$) and were heavier ($P<0.01$) on d 35 than were pigs fed the negative-control diet or fed diets containing fish or poultry meal; the performance of pigs fed the diet containing added synthetic amino acids was intermediate. In addition, pigs fed the positive-control diet had increased ADFI and weighed more ($P<0.01$), compared with pigs fed the other dietary treatments. Pigs fed the diet containing added synthetic amino acids or fed the positive-control diet tended to have improved F/G ($P<0.07$), compared with that of pigs fed the other dietary treatments.

Neither poultry meal nor fish meal improved pig performance from d 7 to 17 or for the overall trial, compared with that of the negative-control diet containing soybean meal. Feeding diets containing added synthetic amino acids improved pig performance from d 7 to 17, compared with feeding diets containing fish meal, poultry meal, or soybean meal; but overall performance was slightly lower than that of pigs fed the positive-control diet containing both fish meal and blood meal. Using synthetic amino acids to replace specialty protein sources, such as fish meal and poultry meal, may be a viable option in current phase 2 nursery diets.

Table 1. Diet Composition (As-fed Basis)[ab]

Ingredient, %	Negative Control	Positive Control	Fish	Poultry	Synthetic Amino Acids
Corn	43.00	50.74	46.90	46.00	52.60
Soybean meal, 46.5% CP	40.70	30.25	33.24	33.38	30.16
Spray-dried whey	10.00	10.00	10.00	10.00	10.00
Choice white grease	3.00	1.00	1.00	1.00	1.00
Monocalcium phosphate, 21% P	1.50	1.20	1.00	1.00	1.50
Fish meal	-	2.25	4.50	-	-
Blood meal		0.83			
Poultry meal	-	-	-	5.00	-
Limestone	0.95	0.55	0.68	0.88	0.93
Salt	0.30	0.30	0.30	0.30	0.30
Vitamins and trace minerals[b]	0.30	0.30	0.30	0.30	0.30
L-Lysine HCl	0.15	0.30	0.15	0.15	0.53
DL-Methionine	0.10	0.15	0.18	0.18	0.27
L-Threonine	-	0.14	-	-	0.25
L-Isoleucine	-	-	-	-	0.10
L-Valine	-	-	-	-	0.13
L-Tryptophan	-	-	-	-	0.03
Calculated Analysis					
Total lysine, %	1.55	1.55	1.55	1.55	1.55
True-ileal-digestible amino acids					
Lysine, %	1.40	1.40	1.40	1.40	1.40
Isoleucine:lysine ratio, %	68.0	65.0	66.0	61.0	58.0
Leucine:lysine ratio, %	130.0	123.0	128.0	130.0	110.0
Methionine:lysine ratio, %	31.0	33.0	32.0	31.0	38.0
Met & Cys:lysine ratio, %	56.0	56.0	56.0	56.0	60.0
Threonine:lysine ratio, %	59.0	62.0	58.0	58.0	65.0
Tryptophan:lysine ratio, %	20.0	17.1	18.0	19.0	17.1
Valine:lysine ratio, %	72.0	67.0	71.0	72.0	67.0
ME, kcal/lb	1,550	1,561	1,564	1,559	1,552
CP, %	23.8	21.8	23.5	23.9	19.7
Ca, %	0.90	0.77	0.87	0.87	0.90
P, %	0.75	0.72	0.73	0.72	0.72
Available P, %	0.43	0.43	0.43	0.43	0.43

[a]All diets fed in meal form.

[b]Pigs fed experimental diets from d 7 to d 17 after weaning and a common diet from d 17 to d 35.

Table 2. Effect of Replacing Fish Meal or Poultry Meal with Synthetic Amino Acids in Phase 1 Nursery Diets[a]

Item	Negative Control	Positive Control	Fish	Poultry	Synthetic Amino Acids	SE	P-value
Day 7 to 17							
ADG, lb	0.43[c]	0.51[b]	0.41[c]	0.40[c]	0.48[b]	0.02	0.0005
ADFI, lb	0.68	0.71	0.67	0.66	0.70	0.02	0.34
F/G	1.60[c]	1.39[b]	1.63[c]	1.69[c]	1.45[b]	0.05	0.0002
Day 17 to 35							
ADG, lb	0.91	0.95	0.89	0.88	0.90	0.03	0.17
ADFI, lb	1.26[c]	1.34[b]	1.25[c]	1.22[c]	1.24[c]	0.03	0.01
F/G	1.38	1.41	1.40	1.38	1.37	0.02	0.43
Day 7 to 35							
ADG, lb	0.74[cd]	0.79[b]	0.72[cd]	0.71[d]	0.75[bc]	0.02	0.01
ADFI, lb	1.05[c]	1.11[b]	1.04[c]	1.02[c]	1.04[c]	0.03	0.01
F/G	1.42	1.41	1.44	1.44	1.39	0.02	0.07
Day 17 wt	18.7[c]	19.5[b]	18.5[c]	18.4[c]	19.2[b]	0.20	0.01
Day 35 wt	35.2[de]	36.8[b]	34.8[de]	34.4[e]	35.5[cd]	0.60	0.01

[a]Each value is the mean of six replications with two pens of 25 pigs per pen sharing a common fence-line feeder as the experimental unit (initially 14.5 lbs of BW). Experimental diets fed from d 7 to d 17, and a common diet was fed from d 17 to d 35 after weaning.
[b,c,d,e]Means having different superscript letters within a row differ ($P<0.05$).

DETERMINATION OF THE APPARENT AND TRUE ILEAL AMINO ACID DIGESTIBILITY AND DIGESTIBLE AND METABOLIZABLE ENERGY OF SPECIALTY PROTEIN SOURCES INTENDED FOR NURSERY PIG DIETS[1]

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Summary

Two experiments were conducted to determine the apparent and true-ileal amino acid digestibility, and to determine the digestible energy and metabolizable energy values of rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried animal plasma. The experimental ingredients were analyzed for essential and non-essential amino acids and crude protein so diets could be formulated. In Exp.1, pigs were fed each diet, and ileal digesta was collected and analyzed. Apparent and true digestibilities were then calculated. In Exp. 2, pigs were fed each diet and feces were collected, weighed, and sampled. Lab analyses were conducted for the determination of gross energy (GE) and digestible energy (DE). Then ME values were determined by calculation from the DE and CP concentrations of experimental diets. In Exp. 1, TID lysine, methionine, and threonine values were 86.6, 69.0, and 78.9% for rice protein concentrate; 89.7, 88.7, and 80.2% for salmon protein hydrolysate; 95.7, 93.9, and 88.4% for whey protein concentrate; and 95.4, 93.5, and 92.2% for spray-dried animal plasma, respectively. In Exp. 2, DE values for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried animal plasma were 2143, 1893, 2245, and 2062 kcal/lb, respectively. The ME values that were determined for the protein products were 1917, 1598, 1974, and 1805 kcal/lb, respectively.

(Key Words: Digestibility, Pigs, Rice Protein Concentrate, Salmon Protein Hydrolysate, Whey Protein Concentrate, Spray-dried Animal Plasma.)

Introduction

The inclusion of high-quality protein ingredients in nursery-pig diets is a common practice among nutritionists across the world. As new protein products are developed, however, reliable and accurate digestibility and energy values must be determined so nutritionists have greater confidence in these products when using them in diets. Although new protein products may have greater amounts of protein and amino acids, the true digestibility of these amino acids needs to be established for proper diet formulation to ensure that the nutritional needs of the newly weaned pig are being met.

There are no currently published data for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, or spray-dried animal plasma for true ileal amino acid

[1]The authors thank Sven Gravendeel of International Quality Ingredients, The Netherlands, for donation of the rice protein concentrate and salmon protein hydrolysate and forpartial funding of this experiment.
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digestibilities, and only spray-dried animal plasma has published apparent ileal amino acid digestibility values. Also, rice protein concentrate, salmon protein hydrolysate, and whey protein concentrate lack digestible and metabolizable energy values.

The objective of this experiment was to determine the apparent and true ileal amino acid digestibility, and determine digestible and metabolizable energy values for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried animal plasma.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved protocols used in this experiment.

Experiment 1. Six barrows (initially 65 lb) were surgically fitted with simple T-cannulas approximately 15 cm anterior to the ileocecal valve. Pigs were housed in stainless-steel metabolism cages and were randomly allotted to one of four dietary treatments in a balanced crossover design. Diets were formulated to 12.5% protein by using analyzed nutrient compositions of the four experimental treatments (Table 1). The diets used in Exp.1 were based on corn starch and contained either rice protein concentrate, salmon protein hydrolysate meal, whey protein concentrate, or spray-dried animal plasma (Table 2). All diets contained 0.25% chromic oxide as an indigestible marker.

Each 7-d feeding period consisted of a 6-d acclimation period followed by 1 day (12h/d) of ileal digesta collection. Feed was divided into two equal meals and fed at 0600 and 1800 each day. Pigs were weighed each week, and feed allowance was calculated to maintain intakes of 2.5% of BW. Water was provided at a rate of 2:1 water:feed (wt:wt). The average weight of the pigs at the end of the experiment was 92 lb.

Ileal digesta was collected between 0600 and 1800 for one day during each period by attaching a latex balloon to the cannula. Digesta in the balloon was collected periodically and stored under refrigeration during the 12-h collection period. At the end of each day's collection, the digesta was frozen and stored. At the conclusion of collection for the experiment, digesta from each pig, in their respective periods, were homogenized and a 200-g subsample was taken. The samples were then freeze-dried and ground for analysis. All nutrient digestibilities were calculated by using chromic oxide as the indigestible marker.

Experiment 2. Six barrows (initially 82.9 lb) were used to determine DE and ME values for the four experimental ingredients. Pigs were housed in stainless-steel metabolism cages designed to allow separate collection of feces. Pigs were allotted to one of five dietary treatments in a balanced crossover design. The four experimental ingredients were from the same batches as those used in Exp. 1. Diets were formulated to contain approximately 20.0% CP, except for the corn control diet. Because the corn in each diet also supplied energy, a fifth diet was fed to determine the energy value of corn so the DE and ME of the experimental diets and protein products could be calculated by difference.

Feed was divided into two equal meals and fed at 0600 and 1800 each day. Pigs were weighed every week and feed allowance was calculated to maintain daily intakes of 3.0% of BW. Water was provided twice daily at a rate of 2:1 water:feed (wt:wt). The average weight of the pigs at the end of period 5 was 112.2 lb.

The five feeding periods consisted of 3 days of diet acclimation followed by 4 days of total fecal collection. Feces were collected twice daily and later pooled for each period. The feces then were mixed, dried, and ground, from which a representative subsample was taken. This subsample was ground once more and used for analysis. Ferric oxide (1% of

diet) was used as the indigestible marker to identify the beginning and end of each collection period. Feed and feces were analyzed for GE by using adiabatic bomb calorimetry.

The DE values of protein products were then calculated by subtracting gross energy excreted from gross energy intake. This value was then expressed as a percentage and multiplied by the GE value for the feed, and shown in kcal/lb (Table 5).

For ME values of each ingredient, the equation below was used, based on the DE and CP of diets containing each protein product. Individual ME values were then calculated by difference from the ME value determined from the corn used in the diets.

$$ME = DE \times (1.003 - (0.0021 \times \%CP))$$
$$R^2 = 0.48$$

Results and Discussion

Analyzed nutrient compositions of each protein product are reported in Table 1. Crude protein values ranged from a low of 67.51% for rice protein concentrate to a high of 92.70% for salmon protein hydrolysate.

Apparent-ileal-digestible (AID) lysine, methionine, and threonine values were 80.0, 65.6, and 68.4% for rice protein concentrate; 85.6, 85.5, and 69.8% for salmon protein hydrolysate; 93.3, 89.9, and 83.6% for whey protein concentrate; and 92.8, 85.7, 86.5% for spray-dried animal plasma, respectively.

The TID lysine, methionine, and threonine values were 86.6, 69.0, and 78.9% for rice protein concentrate; 89.7, 88.7, and 80.2% for salmon protein hydrolysate; 95.7, 93.9, and 88.4% for whey protein concentrate; and 95.4, 93.5, 92.2% for spray-dried animal plasma, respectively.

Digestible-energy values for rice protein concentrate, salmon protein hydrolysate, whey protein concentrate, and spray-dried animal plasma were 2143, 1893, 2245, and 2062 kcal/lb, respectively. Metabolizable energy values for the ingredients were 1917, 1598, 1974, 1805 kcal/lb, respectively.

Apparent and true amino acid digestibility values were established for specialty protein products for nursery pigs. Although amino acid digestibility values did differ, all protein products tested seem to have high amino acid utilization in swine diets. Although the use of spray-dried animal plasma and whey protein concentrate for nursery pigs has been researched, use of rice protein concentrate and salmon protein hydrolysate has not. Further research to determine growth performance of nursery pigs fed these protein products is needed for practical application by nutritionists.

Table 1. Analyzed Nutrient Composition of Ingredients (As-fed Basis)

Nutrient	Rice Protein Concentrate	Salmon Protein Hydrolysate	Whey Protein Concentrate	Spray-dried Animal Plasma
DM, %	92.68	91.44	94.69	90.85
CP, %	67.51	92.70	80.18	77.95
Ash, %	3.41	6.84	2.46	8.60
Amino Acids, %:				
Arginine	5.26	5.47	2.03	4.57
Histidine	1.65	1.59	1.56	2.61
Isoleucine	2.91	2.16	5.15	2.90
Leucine	5.31	3.97	8.69	7.51
Lysine	2.21	5.05	7.49	6.90
Methionine	1.77	1.89	1.64	0.69
Phenylalanine	3.52	2.10	2.65	4.38
Threonine	2.12	2.62	5.01	4.33
Tryptophan	0.81	0.48	1.61	1.38
Valine	4.13	2.78	4.82	5.20
Alanine	3.47	5.93	3.81	4.18
Aspartic acid	5.39	6.18	8.21	7.35
Cysteine	1.45	0.42	1.83	2.73
Glutamic acid	10.87	10.01	13.80	11.53
Glycine	2.77	11.99	1.44	2.76
Proline	2.94	6.17	4.92	4.44
Serine	2.36	2.60	2.96	3.98
Tyrosine	3.32	1.32	2.38	4.04

Table 2. Diet Composition (Exp. 1; As-fed Basis)

Ingredient, %	Protein Free	Rice Protein Concentrate	Salmon Protein Hydrolysate	Whey Protein Concentrate	Spray-dried Animal Plasma
Corn starch	80.80	74.12	79.59	70.46	70.95
Rice protein concentrate	---	18.55	---	---	---
Salmon protein hydrolysate	---	---	13.48	---	---
Whey protein concentrate	---	---	---	16.60	---
Spray dried animal plasma	---	---	---	---	16.45
Sucrose	10.00	---	---	---	---
Solca floc	3.00	---	---	6.00	6.00
Soy oil	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.45	2.85	2.20	2.55	1.55
Limestone	0.30	0.48	0.75	0.38	1.05
Salt	0.40	0.35	0.35	0.35	0.35
Vitamin premix	0.05	0.25	0.25	0.25	0.25
Trace mineral premix	0.25	0.15	0.15	0.15	0.15
Potassium chloride	0.40	---	---	---	---
Magnesium chloride	0.10	---	---	---	---
Chromic oxide	0.25	0.25	0.25	0.25	0.25
TOTAL	100.00	100.00	100.00	100.00	100.00
Calculated Analysis[a]					
Total lysine, %	0.01	0.41	0.68	1.25	1.14
CP, %	0.06	12.50	12.50	12.50	12.50
Ca, %	0.38	0.71	0.71	0.72	0.71
P, %	0.31	0.60	0.60	0.60	0.61
Available P, %	0.31	0.60	0.53	0.59	0.58

[a]Based on analyzed values reported in Table 1.

Table 3. Diet Composition (Exp. 2; As-fed Basis)

Ingredient, %	Rice Protein Concentrate	Salmon Protein Hydrolysate	Whey Protein Concentrate	Spray-dried Animal Plasma	Corn Control[a]
Corn	75.97	82.51	78.82	79.42	96.18
Rice protein concentrate	20.05	---	---	---	---
Salmon protein hydrolysate	---	13.98	---	---	---
Whey protein concentrate	---	---	17.70	---	---
Spray-dried animal plasma	---	---	---	17.45	---
Monocalcium phosphate, 21% P	2.10	1.30	1.73	0.60	1.80
Limestone	0.90	1.23	0.78	1.55	1.03
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15
Chromic oxide	0.25	0.25	0.25	0.25	0.25
TOTAL	100.00	100.00	100.00	100.00	100.00
Calculated Analysis[b]					
Total lysine, %	0.64	0.92	1.53	1.41	0.00
CP, %	20.00	20.00	20.90	20.30	8.20
Ca, %	0.75	0.75	0.75	0.75	0.75
P, %	0.65	0.65	0.65	0.65	0.65
Available P, %	0.47	0.38	0.46	0.43	0.42

[a]The corn diet was used to determine the energy value of corn, so energy values of the test protein products could be determined by difference.
[b]Based on analyzed values reported in Table 1.

Table 4. Apparent and True-ileal Digestibility of Ingredients (Exp. 1)[a]

	Rice Protein Concentrate		Salmon Protein Hydrolysate		Whey Protein Concentrate		Spray-dried Animal Plasma	
Amino Acids	AID, %[b]	TID, %[c]	AID, %	TID, %	AID, %	TID, %	AID, %	TID, %
Arginine	86.8	89.9	90.6	94.6	86.0	94.5	92.7	96.8
Histidine	80.0	82.9	78.5	81.8	88.0	90.9	91.8	93.5
Isoleucine	75.6	80.7	72.2	81.2	90.8	94.3	87.1	92.8
Leucine	75.5	79.3	76.1	82.9	92.3	95.2	90.6	93.7
Lysine	80.0	86.6	85.6	89.7	93.3	95.7	92.8	95.4
Methionine	65.6	69.0	85.5	88.7	89.9	93.9	85.7	93.5
Phenylalanine	77.4	80.5	73.2	80.4	84.7	90.0	89.4	92.5
Threonine	68.4	78.9	69.8	80.2	83.6	88.4	86.5	92.2
Tryptophan	84.7	103.9	65.4	104.8	92.3	102.2	91.2	101.0
Valine	76.0	81.3	73.7	83.4	87.4	92.5	89.2	93.8
Alanine	74.0	79.5	84.5	88.8	85.2	91.4	87.6	93.3
Aspartic acid	77.2	81.2	66.1	68.5	89.9	93.1	87.9	91.4
Cysteine	64.7	63.5	38.2	33.9	86.4	84.8	91.0	90.0
Glutamic acid	72.8	74.6	83.3	86.3	90.2	92.1	90.3	92.7
Glycine	72.7	84.6	84.2	87.9	52.6	76.0	74.6	87.8
Proline	69.5	77.8	81.4	86.6	83.9	89.9	87.8	93.7
Serine	73.3	79.7	79.5	86.6	84.7	89.8	88.7	93.5
Tyrosine	72.3	76.9	62.7	73.9	80.6	86.0	90.7	93.9

[a]Values are the means of six pigs (initially 65 lb) used in a balanced crossover design.
[b]Apparent ileal digestibility.
[c]True ileal digestibility.

Table 5. Diet Energy Density (Exp. 2; As-fed Basis)

Ingredient, %	Rice Protein Concentrate	Salmon Protein Hydrolysate	Whey Protein Concentrate	Spray-dried Animal Plasma	Corn
Gross energy, kcal/lb	2247	2181	2379	2099	1841
Digestibility energy, kcal/lb	2143	1893	2245	2062	1511
Metabolizable energy, kcal/lb	1917	1598	1974	1805	1489

[a]The corn diet was used to determine the energy value of corn, so energy values of the test protein products could be determined by difference.

A COMPARISON OF WHEY PROTEIN CONCENTRATE AND SPRAY-DRIED ANIMAL PLASMA IN DIETS FOR WEANLING PIGS[1]

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Summary

A total of 180 weanling pigs (initially 13.7 lb and 21 ± 3 d of age, PIC L326 × C22) were used to evaluate the effects of whey protein concentrate or spray-dried animal plasma on growth performance of weanling pigs. Pigs were fed one of five experimental diets: negative control with no specialty protein sources, or the control diet with 2.5% spray-dried animal plasma (SDAP), 5.0% spray-dried animal plasma, 2.5% whey protein concentrate (WPC), or 5.0% whey protein concentrate. Pigs were fed the experimental diets from d 0 to 14 after weaning, then all pigs were fed a common phase 2 diet from d 14 to 27 after weaning. From d 0 to 14, increasing SDAP increased ADG and ADFI (linear, P<0.01). Increasing WPC had no effect on ADG and ADFI, but increased F/G (quadratic, P<0.01). The mean ADG and ADFI of pigs fed diets containing SDAP was greater (P<0.01) than the mean of pigs fed diets containing WPC. Overall (d 0 to 27 after weaning), increasing SDAP from d 0 to 14 increased ADG (linear, P<0.03) and tended to increase ADFI (linear, P<0.11). Increasing WPC from 0 to 14 had no effect on overall ADG or F/G. Pigs fed diets containing SDAP from d 0 to 14 had greater overall ADG (P<0.03) and tended to have improved F/G (P<0.12) compared with ADG and F/G of pigs fed WPC. The inclusion of spray-dried animal plasma during the first 14 d after weaning improved overall growth performance; the inclusion of whey protein concentrate did not.

(Key Words: Nursery Pigs, Pigs, Spray-dried Animal Plasma, Whey Protein Concentrate.)

Introduction

Spray-dried animal plasma (SDAP) has previously been shown to improve growth performance in early weaned nursery pigs. Earlier research has also shown that high-protein whey protein concentrate (WPC) also improves growth performance of nursery pigs. The objectives of this study were to compare the effects spray-dried animal plasma and a high-protein whey protein concentrate (a different source than what was used in earlier studies) on growth performance in nursery-pig diets, and to determine if whey protein concentrate can replace spray-dried animal plasma in nursery diets.

Procedures

A total of 180 weanling pigs (13.8 lb and 18 ± 3 d of age, PIC L326 × C22) were blocked by initial weight and were randomly allotted to one of five dietary treatments. There were six pigs per pen and six pens per

[1]The authors thank Peter Gutierrez, Agri-Mark, Inc., Onalaska, WI, for donation of whey protein concentrate and whey permeate used in this experiment.
[2]Food Animal Health and Management Center.

treatment. All pigs were fed phase 1 treatment diets from weaning to d 14 after weaning. There were five experimental diets: negative control with no specialty protein sources, and control diet with 2.5% SDAP, 5.0% SDAP, 2.5% WPC, or 5.0% WPC. All pigs were then fed the same common phase 2 diet from d 14 to 27 after weaning.

All diets were fed in meal form (Table 1). Phase 1 (d 0 to 14 after weaning) diets were formulated to contain 1.50% lysine, 0.85% Ca, and 0.50% available phosphorus. Phase 2 (d 14 to 27 after weaning) diets were formulated to contain 1.45% lysine, 0.82% Ca, and 0.45% available phosphorus. The trial was conducted in an environmentally controlled nursery facility at the Kansas State University Swine Teaching and Research Center. Each pen was 5 × 5 ft and contained one self-feeder and one nipple waterer to provide ad libitum access to feed and water. Pigs and feeders were weighed on d 7, 14, and 27 after weaning to determine ADG, ADFI, and F/G. Data were analyzed as a randomized complete-block design, with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS.

Results and Discussion

From d 0 to 7, 7 to 14, and 0 to 14, increasing SDAP increased ADG and ADFI (linear, $P<0.01$). Increasing WPC had no effect on ADG or ADFI ($P>0.10$) and tended to increase F/G ($P<0.06$).

From d 14 to 27, pigs previously fed diets containing SDAP tended to have poorer F/G (quadratic, $P<0.09$). No differences were observed in ADG or ADFI ($P>0.18$). Pigs previously fed diets containing WPC did not have improved growth performance compared with pigs previously fed diets containing SDAP.

Overall (d 0 to 27 after weaning), increasing SDAP from d 0 to 14 increased ADG (linear, $P<0.03$) and tended to increase ADFI (linear, $P<0.11$). Increasing WPC did not have an effect on ADG or ADFI. Also, pigs fed diets containing SDAP from d 0 to 14 tended to have improved F/G ($P<0.12$) compared with pigs fed WPC.

In conclusion, pigs fed diets containing SDAP had improved growth performance, whereas those fed WPC did not. This is in contradiction to previously reported data with pigs fed WPC, but the source of WPC used in this trial was different than in earlier studies. This may be an indication of product variation and differences in manufacturing processes between sources.

Table 1. Analyzed Nutrient Composition of Ingredients (As-fed Basis)[a]

Nutrient	Whey Protein Concentrate	Spray-Dried Animal Plasma
DM, %	94.69	90.85
CP, %	80.18	77.95
Ash, %	2.46	8.60
Amino Acids, %		
Arginine	2.03	4.57
Histidine	1.56	2.61
Isoleucine	5.15	2.90
Leucine	8.69	7.51
Lysine	7.49	6.90
Methionine	1.64	0.69
Phenylalanine	2.65	4.38
Threonine	5.01	4.33
Tryptophan	1.61	1.38
Valine	4.82	5.20
Alanine	3.81	4.18
Aspartic acid	8.21	7.35
Cysteine	1.83	2.73
Glutamic acid	13.80	11.53
Glycine	1.44	2.76
Proline	4.92	4.44
Serine	2.96	3.98
Tyrosine	2.38	4.04

[a]Values represent the means of one sample for each ingredient, analyzed in duplicate.

Table 2. Diet Composition (As-fed Basis)

	Phase 1[a]					Phase 2[b]
		SDAP[c]		WPC[d]		
Ingredient, %	Control	2.50 %	5.00 %	2.50%	5.00 %	
Corn	41.50	45.10	48.67	45.55	49.57	50.53
Soybean meal, 46.5% CP	40.32	34.30	28.28	33.78	27.23	32.39
Spray dried whey	15.00	15.00	15.00	15.00	15.00	---
Spray dried animal plasma	---	2.50	5.00	---	---	---
Whey protein concentrate	---	---	---	2.50	5.00	---
Whey permeate	---	---	---	---	---	8.50
Select menhaden fish meal	---	---	---	---	---	2.50
Soy oil	---	---	---	---	---	2.00
Monocalcium phosphate, 21% P	1.50	1.35	1.20	1.50	1.50	1.20
Limestone	0.83	0.93	1.05	0.83	0.85	0.70
Salt	0.30	0.30	0.30	0.30	0.30	0.35
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Zinc oxide	---	---	---	---	---	0.25
Neo-Terramycin	---	---	---	---	---	0.70
L-Threonine	---	---	---	---	---	0.13
Lysine HCl	0.05	0.05	0.05	0.05	0.05	0.20
DL -Methionine	0.10	0.08	0.05	0.10	0.10	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis						
Total lysine, %	1.50	1.50	1.50	1.50	1.50	1.45
ME, kcal/lb	1,483	1,490	1,496	1,482	1,482	1,458
CP, %	24.1	23.5	23.0	23.4	22.7	21.3
Ca, %	0.85	0.85	0.85	0.85	0.85	0.82
P, %	0.82	0.80	0.78	0.79	0.77	0.75
Available P, %	0.50	0.50	0.50	0.50	0.50	0.45

[a]Phase 1 fed from d 0 to 14 post-weaning.
[b]Phase 2 fed from d 14 to 28 post-weaning.
[c]Spray-dried animal plasma.
[d]Whey protein concentrate.

Table 3. Growth Performance of Nursery Pigs Fed either Spray-dried Animal Plasma or Whey Protein Concentrate[a]

						Probability, P <					
		SDAP[b]		WPC[c]		SDAP[b]		WPC[c]			
Item	Control	2.50%	5.00%	2.50%	5.00%	Linear	Quadratic	Linear	Quadratic	SDAP vs WPC	SE
Day 0 to 7											
ADG, lb	.51	.53	.67	.46	.48	.01	.19	.67	.47	.01	.05
ADFI, lb	.49	.57	.66	.54	.52	.01	1.00	.37	.27	.01	.04
F/G	1.01	1.10	1.00	1.19	1.10	.87	.17	.26	.06	.09	.08
Day 7 to 14											
ADG, lb	.58	.61	.71	.62	.61	.03	.46	.69	.65	.20	.05
ADFI, lb	.78	.86	.99	.88	.79	.01	.59	.82	.05	.03	.05
F/G	1.34	1.41	1.40	1.44	1.32	.37	.46	.65	.04	.59	.06
Day 0 to 14											
ADG, lb	.54	.57	.69	.54	.54	.01	.19	1.00	.88	.01	.04
ADFI, lb	.63	.72	.82	.71	.66	.01	.73	.58	.08	.01	.04
F/G	1.18	1.26	1.20	1.33	1.21	.77	.11	.57	.01	.28	.05
Day 14 to 27											
ADG, lb	1.37	1.44	1.43	1.41	1.35	.35	.37	.67	.31	.18	.05
ADFI, lb	1.44	1.57	1.54	1.50	1.40	.91	.31	.26	.25	.98	.10
F/G	1.05	1.09	1.08	1.07	1.04	.41	.09	.40	.79	.23	.07
Day 0 to 27											
ADG, lb	.94	.99	1.04	.96	.93	.03	.91	.80	.59	.03	.04
ADFI, lb	1.44	1.44	1.54	1.50	1.40	.11	.37	.50	.13	.33	.06
F/G	1.53	1.47	1.48	1.57	1.50	.38	.45	.63	.26	.12	.06

[a]A total of 180 weanling pigs (initially 13.7 lb and 21 ± 3 d of age), with six pigs per pen and six pens per treatment.
[b]Spray-dried animal plasma.
[c]Whey protein concentrate.

EFFECTS OF INCREASING EXTRUDED SOY-PROTEIN CONCENTRATE ON GROWTH PERFORMANCE OF NURSERY PIGS[1]

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Summary

Two hundred and forty barrows and gilts (initially 13.0 lb and 18 ± 2 d of age at weaning) were blocked by initial weight and were allotted randomly to one of five dietary treatments. There were eight replications (pens) per treatment, with six pigs per pen. Pigs were fed experimental diets from d 0 to 14 after weaning that included a control diet containing 40% soybean meal and diets containing 7.1, 14.3, 21.4, or 28.6% extruded soy-protein concentrate. From d 14 to 28, all pigs were fed a similar diet to determine if any carry-over effects existed from the treatment diets.

From d 0 to 14, ADG and ADFI increased (quadratic, P<0.06) as extruded soy protein concentrate increased from 7.1 to 21.4%, and then decreased similar to control values when 28.6% extruded soy-protein concentrate was fed. Feed efficiency improved (linear, P<0.01) with increasing rates of extruded soy-protein concentrate in the diet. Overall (d 0 to 28), there were no differences observed for ADG or ADFI, but F/G improved (linear, P<0.01) as extruded soy-protein concentrate increased in the diet. These results indicate that an inclusion rate up to 21.4% of extruded soy-protein concentrate was optimal for nursery-pig performance during the first two weeks post-weaning.

(Key Words: Growth, Extruded Soy Protein Concentrate, Pigs, Weanling Pigs.)

Introduction

Commercial diets for early weaned pigs currently contain relatively low concentrations of soybean meal. It has been suggested that the transient hypersensitivity response to beta-conglycinin and conglycinin contained in soybean meal limits its inclusion in starter diets. A greater inclusion of soy proteins may be possible without negatively affecting pig performance because soy proteins are produced by different processing methods than those for soybean meal. Therefore, further-processed soy proteins such as extruded soy-protein concentrates may be alternatives to animal-based protein sources. Soy-protein concentrates are produced from defatted soy flakes. Soluble carbohydrates, primarily sucrose, raffinose, and stachyose, are removed from the defatted flakes. In previous trials (Swine Day 2003 Report of Progress), we have observed that pigs fed greater than 14% extruded soy-protein concentrate in diets immediately after weaning had decreased ADG compared with that of pigs fed soybean meal. It seemed that high rates of extruded soy-protein concentrate (28%) as a complete replacement for soybean meal negatively affected feed intake. There-

[1]The authors thank The Solae Co., Decatur, IL, for providing the Profine E used in this trial.
[2]Food Animal Health and Management Center.

fore, this experiment was designed to follow up our previous studies and to determine the optimal concentration of extruded soy-protein concentrate (Profine E) in nursery-pig diets.

Procedures

Two hundred and forty barrows and gilts (Line 327 sire × C42 dams; PIC; initially 13.0 lb and 18 ± 2 d of age at weaning) were blocked by initial weight and were allotted randomly to one of five dietary treatments. There were eight replications (pens) per treatment, with six pigs per pen. The experiment was conducted at the Kansas State University Swine Teaching and Research Center. Each pen (5 × 4 ft) had slatted metal flooring and contained a stainless steel self-feeder and one nipple waterer to allow ad libitum consumption of feed and water.

Pigs were fed experimental diets from d 0 to 14 after weaning that included a control diet containing 40% SBM and diets containing 7.1, 14.3, 21.4, or 28.6% extruded soy-protein concentrate (Profine E; Table 1). From d 14 to 28, all pigs were fed the same phase 2 diet formulated to contain 1.5% total lysine (Table 1). Diets were formulated to meet or exceed the nutrient requirements of pigs. Pigs and feeders were weighed every 7 d to determine ADG, ADFI, and feed efficiency (F/G).

Data were analyzed as a randomized complete-block design with pen as the experimental unit. Pigs were blocked based on weaning weight, and analysis of variance was performed by using the PROC MIXED procedure of SAS. Linear and quadratic polynomial contrasts were performed to determine the effects of increasing extruded soy-protein concentrate.

Results

From d 0 to 14 post-weaning, an increase in ADG (quadratic, $P<0.06$) and ADFI (quadratic, $P < 0.04$) was observed as extruded soy protein concentrate increased to 21.4% of the diet (Table 2). But both ADG and ADFI decreased to control values when pigs were fed 28.6% extruded soy-protein concentrate. Feed efficiency improved (linear, $P<0.01$) as extruded soy-protein concentrate increased to 28.6%.

From d 14 to 28 post-weaning, when all pigs were fed the same phase 2 diet, there were no differences in ADG, ADFI, or F/G. Overall (d 0 to 28), there were no differences observed for ADG or ADFI. Feed efficiency improved (linear, $P<0.01$) as extruded soy-protein concentrate increased to 28.6% of the diet.

Conclusions from this study, combined with the findings in the Swine Day 2003 Report of Progress, indicate that nursery pigs can be fed as much as to 21.4% extruded soy protein concentrate post-weaning to maximize growth rate. Higher dietary rates have resulted in improved feed efficiency, but consistently reduced nursery-pig growth rate.

Table 1. Diet Composition (As-fed Basis)

		Extruded Soy-Protein Concentrate, %				
Ingredient, %	40% SBM	7.1	14.3	21.4	28.6	Phase 2
Corn	32.96	35.92	38.91	41.87	44.34	51.17
Soybean meal, 46.5% CP	40.00	29.90	19.75	9.65	---	27.30
Soy oil	2.50	2.50	2.50	2.50	2.50	3.00
Extruded soy protein concentrate[a]	---	7.14	14.28	21.42	28.55	---
Spray dried whey	20.00	20.00	20.00	20.00	20.00	10.00
Monocalcium phosphate, 21% P	1.38	1.39	1.40	1.41	1.45	0.90
Limestone	0.93	0.93	0.94	0.95	0.98	0.60
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Medication[b]	1.00	1.00	1.00	1.00	1.00	1.00
Zinc oxide	0.38	0.38	0.38	0.38	0.38	0.25
L-lysine HCl	0.05	0.04	0.04	0.03	0.01	0.30
DL-methionine	0.10	0.10	0.10	0.09	0.09	0.15
L-threonine	---	---	---	---	---	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.00
Calculated Analysis:						
Total lysine, %	1.51	1.51	1.51	1.51	1.51	1.50
Isoleucine:lysine ratio, %	72	73	74	75	77	61
Leucine:lysine ratio, %	133	135	137	139	142	121
Methionine:lysine ratio, %	30	30	30	30	30	34
Met & Cys:lysine ratio, %	57	57	57	58	57	58
Threonine:lysine ratio, %	65	66	67	68	70	65
Tryptophan:lysine ratio, %	21	20	20	19	19	17
Valine:lysine ratio, %	77	78	80	81	83	68
ME, kcal/lb	1,513	1,513	1,513	1,513	1,513	1,545
CP, %	23.8	24.0	24.2	24.4	24.7	21.1
Ca, %	0.90	0.90	0.89	0.89	0.90	0.81
P, %	0.80	0.80	0.80	0.79	0.80	0.73
Lysine:calorie ratio, g/mcal	4.53	4.53	4.53	4.53	4.53	4.40

[a]Profine E.
[b]Provided 55 mg/kg carbadox per ton of complete feed.

Table 2. Effect of Increasing Extruded Soy-Protein Concentrate on Growth Performance of Weanling Pigs[a]

		Extruded Soy-Protein Concentrate, %					Probability (P<)	
Item	40% SBM	7.1	14.3	21.4	28.6	SED	Linear	Quadratic
Day 0 to 14								
ADG, lb	.72	.74	.78	.78	.72	0.03	0.81	0.06
ADFI, lb	.80	.83	.83	.85	.73	0.51	0.33	0.04
F/G	1.09	1.11	1.04	1.08	1.00	0.02	0.01	0.28
Day 14 to 28[b]								
ADG, lb	1.39	1.36	1.35	1.36	1.39	0.03	0.93	0.15
ADFI, lb	1.87	1.81	1.83	1.87	1.82	0.50	0.76	0.74
F/G	1.33	1.33	1.35	1.36	1.30	0.02	0.74	0.25
Day 0 to 28								
ADG, lb	1.06	1.05	1.06	1.07	1.06	0.27	0.83	0.77
ADFI, lb	1.33	1.32	1.33	1.36	1.28	0.46	0.44	0.30
F/G	1.20	1.20	1.18	1.20	1.14	0.01	0.01	0.15

[a]A total of 240 pigs (average BW of 13.0 lb), with six pigs per pen and eight pens per treatment with experimental diets fed for 14 d.
[b]All pigs were fed a common phase 2 diet from d 14 to 28.

Swine Day 2004

EVALUATION OF THE OPTIMAL TRUE-ILEAL-DIGESTIBLE LYSINE AND THREONINE REQUIREMENT FOR NURSERY PIGS

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Summary

A total of 1800 pigs (Exp 1, 360; Exp. 2, 1440) were used in two experiments to evaluate the true ileal digestible (TID) lysine and threonine requirement for 24- to 44-lb pigs. In Exp. 1, there were eight pens per treatment, with five pigs (Genetiporc, initially 23.6 lb and 34 d of age) per pen. Experiment 1 was conducted as a combination of two separate trials to simultaneously examine both the TID lysine and threonine requirement, and hence, determine the appropriate threonine-to-lysine ratio. The first part of the trial consisted of five treatments formulated to contain 0.9, 1.0, 1.1, 1.2, or 1.3% TID lysine, with TID threonine at 66% of lysine. The second part consisted of five treatments formulated to 1.3% TID lysine with increasing TID threonine (0.60, 0.66, 0.73, 0.79, or 0.85%). Other amino acids were formulated to either meet or exceed requirement estimates, thereby ensuring lysine and threonine were first limiting. The highest concentrations of both lysine and threonine (1.3% and 0.85%, respectively) were combined in a single diet, which was used in both trials, to give a total of 10 treatments. From d 0 to 17, ADG and feed efficiency (F/G) improved as TID lysine (quadratic, $P<0.02$) and threonine (ADG, linear, $P<0.03$; F/G, quadratic, $P<0.04$) increased. Regression analysis showed that 95% or more of the maximum response was obtained at a TID threonine-to-lysine ratio of approximately 64% for ADG and 66% for F/G. In Exp. 2, there were 48 pigs per experimental unit (2 pens sharing a fenceline feeder) and six replications per treatment. Pigs (PIC, 24 lb and 39 d of age) were fed experimental diets containing 1.1% TID lysine (calculated to be less than their requirement estimate), with added L-threonine to give TID threonine concentrations of 0.55, 0.60, 0.66, 0.72, or 0.77% and TID threonine-to-lysine ratios of 50, 55, 60, 65, and 70%. For the 21-d trial, ADG (quadratic, $P<0.07$) and F/G (quadratic, $P<0.01$) improved with increasing TID threonine. The best ADG and F/G were observed at 0.72% TID threonine. Hence, it seems that pigs weighing between 22 and 44 lb require approximately 0.72% TID threonine (0.81% total threonine) when fed 1.1% TID lysine, which corresponds to a TID threonine-to-lysine ratio of 65%, similar to results in Exp. 1. Data from these two studies indicate an optimal TID threonine-to-lysine ratio of approximately 64 to 66% for 24- to 44-lb pigs.

(Key Words: Lysine, Nursery Pigs, Pigs, Threonine.)

Introduction

There is an increased interest in synthetic threonine supplementation in swine diets because it has become more commercially

[1]Food Animal Health and Management Center.
[2]Anjinomoto-Heartland Lysine, Chicago, IL.

available and economically viable. The current National Research Council (NRC) requirement estimate for true-ileal-digestible lysine and threonine for a 24- to 44-lb pig are 1.01 and 0.63% of the diet, respectively, suggesting a TID threonine-to-lysine ratio of 62%. But lysine and threonine requirement estimates from the NRC are less than those currently being used in commercial production. The objective of these experiments was to determine the optimal ratio of threonine to lysine, and to characterize the optimal use of synthetic threonine in diets to maximize growth performance of the nursery pig.

Procedures

Pigs (Exp. 1, Genetiporc, Saint Bernard, Quebec, Canada; Exp. 2, PIC, Franklin, KY) were housed in environmentally controlled nurseries. In Exp. 1, each pen had slatted metal flooring and contained a stainless-steel self-feeder and one nipple waterer to allow ad libitum consumption of feed and water. In Exp. 2, pens had slatted plastic flooring and contained a stainless-steel self-feeder and one cup waterer to allow ad libitum consumption of feed and water.

Experimental diets were fed for 17 d in Exp. 1 and 21 d in Exp. 2, and were fed in meal form in both experiments (Table 1). Diets were formulated to meet or exceed the nutrient requirements of pigs for all nutrients except lysine and threonine. Ingredient nutrient compositions and TID coefficients provided by the NRC were used in diet formulation. Pigs were weighed and feed disappearance was measured on d 7, 14, and 17 (Exp.1), and every 7 d (Exp. 2) to determine ADG, ADFI, and F/G.

Experiment 1. Three hundred and sixty barrows and gilts (16 ± 2 d of age at weaning) were blocked by weight at 18 d postweaning, and were allotted randomly to one of nine dietary treatments. Each treatment had eight replications (pens) per treatment, with five pigs per pen.

For the first 14 d postweaning, pigs were fed a diet containing 20% spray-dried whey and 1.51% total lysine; a diet containing 1.4% lysine was fed from d 14 to 18. Pigs were fed experimental diets from d 18 to 35 postweaning (23.6 to 45.2 lb). The first part of the trial consisted of five treatments formulated to contain 0.9, 1.0, 1.1, 1.2, or 1.3% TID lysine, with TID threonine at 66% of lysine. The second part consisted of five treatments formulated to 1.3% TID lysine, with increasing TID threonine (0.60, 0.66, 0.73, 0.79, or 0.85%). Cornstarch replaced L-lysine or L-threonine in the control diets to form the dietary treatments. The diets containing 0.9% TID lysine with 0.60% TID threonine, 1.3% TID lysine with 0.60% TID threonine, and 1.3% TID lysine with 0.85% TID threonine were blended to form all other diets.

Blood samples were obtained by venipuncture on d 12 from two randomly selected pigs in each pen after a 3-h period of feed deprivation. All samples were centrifuged (13,800 × *g*) before further preparation. Plasma urea N (PUN) determination was performed on each sample by using an autoanalyzer. Plasma from pigs in the same pen was pooled and prepared by using an EZ:faast™ Amino Acid Analysis Kit (Phenomenex®, Torrance, CA) for gas chromatographic analysis.

Experiment 2. One thousand, four-hundred and forty barrows and gilts (18 ± 2 d of age at weaning) were blocked by gender at 21 d postweaning, and were allotted randomly by pen to one of five dietary treatments. Two pens shared the same feeder, with feeder as the experimental unit. Thus, there were 48 pigs per experimental unit and six replications per treatment. Pigs were fed experimental diets from d 21 to 42 postweaning (24 to 44.5 lb).

Immediately postweaning, all pigs were fed 1.1 lb of a complex diet containing spray-dried animal plasma, fishmeal, spray-dried blood cells and spray-dried whey with 1.69% total lysine, followed by 4 lb of a less complex diet containing 1.55% lysine. The diet containing 1.55% lysine was then fed until initiation of the experiment. All diets were formulated to contain 1.1% TID lysine, which is less than the requirement of 1.4% TID lysine previously established for pigs in this facility. L-threonine was added to provide 0.55, 0.60, 0.66, 0.72 or 0.77% TID threonine. The negative- and positive-control diets containing 0.55 and 0.77% TID threonine, respectively, were blended to form the diets of 0.60, 0.66, and 0.72% TID threonine. Subsamples of each dietary treatment were analyzed for amino acid content, and were within expected analytic variation of expected values.

Statistical Analysis. In Exp. 1, data was analyzed as a randomized complete-block design with pen as the experimental unit. Pigs were blocked on the basis of weight at d 18 postweaning, and analysis of variance was performed by using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Linear and quadratic polynomial contrasts were performed to determine the effects of increasing dietary lysine and threonine.

In Exp. 2, data were analyzed as a randomized complete-block design by using the PROC MIXED procedure of SAS, with feeder used as the experimental unit. Linear and quadratic polynomial contrasts were performed to determine the effects of increasing dietary threonine. A feeder from each of the 0.55, 0.60, and 0.72% treatments was dropped from the analysis due to an unrelated health event that greatly reduced the growth rate of pigs in these pens. Weight of pigs at the start of the experiment on d 21 post-weaning was used as a covariate in the analysis.

Results

Experiment 1

Lysine Trial. Overall, there was an increase in ADG (quadratic $P<0.02$) as dietary lysine increased from 0.9 to 1.3% TID lysine, with the greatest ADG observed at 1.2% TID lysine (Table 2). Feed efficiency improved (quadratic, $P<0.01$) as TID lysine increased to 1.2%, and then F/G plateaued. Plasma urea N, measured on d 12, decreased (linear, $P<0.0001$) as TID lysine increased to 1.2% (Table 3). Plasma lysine concentrations increased (linear, $P<0.01$) with increasing TID lysine. Plasma histidine, isoleucine, phenylalanine, and valine concentrations decreased (linear, $P<0.05$) as TID lysine increased, but plasma methionine increased (linear, $P<0.05$) as TID lysine increased. No changes in other amino acid concentrations were observed as TID lysine increased.

Threonine Trial. Increasing TID threonine increased (linear, $P<0.03$) ADG (Table 2). Feed efficiency also improved (quadratic, $P<0.04$) as TID threonine increased from 0.60% to 0.79%, and F/G did not improve thereafter. Plasma urea N concentration decreased (linear, $P<0.04$) as TID threonine increased (Table 3). Plasma threonine concentration increased (quadratic, $P<0.01$) with increasing TID threonine, but plasma lysine concentrations were unchanged. Plasma isoleucine (linear, $P<0.02$), valine (linear, $P<0.05$) and tyrosine (quadratic, $P<0.05$) concentrations increased as TID threonine increased to 0.79%, then decreased at 0.85% TID threonine.

Average daily gain and F/G improved with increasing TID lysine up to 1.2%, and up to 0.79% TID threonine. Regression analysis revealed that 95% or more of the maximum response was obtained at a TID threonine-to-lysine ratio of approximately 64% for ADG and 66% for F/G. The results suggest that the TID threonine-to-lysine ratio for 24- to 44-lb pigs is approximately 64% to 66%.

Experiment 2

Overall, there was an increase in ADG (quadratic, $P<0.07$) as TID threonine increased from 0.55 to 0.72% (Table 4). Feed efficiency also improved (quadratic, $P<0.01$) with increasing TID threonine. With a lysine concentration of 1.1% TID lysine, and a TID threonine requirement of 0.72%, a TID threonine-to-lysine ratio of 65% was determined.

Discussion

The NRC currently suggests a TID threonine-to-lysine ratio of 62% for a 24- to 44-lb pig. This estimate is derived from many trials that investigated the optimal threonine-to-lysine ratio by titrating different threonine concentrations in diets containing a predetermined lysine concentration; this approach is similar to the approach used in our second experiment. Other trials have examined lysine and threonine requirements separately. There are potential problems with this approach to determine a ratio, because a certain lysine concentration is chosen without knowledge of the actual lysine requirement for the specific group of pigs used in the various studies. Therefore, extrapolating a ratio for an amino acid relative to lysine can be biased by the lysine concentration assumed to be the requirement. Experiment 1 was run as a combination of two separate trials in which the TID lysine and TID threonine requirements were examined simultaneously to determine the threonine-to-lysine ratio. This approach to determining an optimal ratio offers greater accuracy because lysine and threonine requirements for a group of pigs are determined simultaneously.

Experiment 1 suggests a TID lysine requirement of 1.2% for a 24- to 44-lb pig. This requirement is greater than the TID lysine requirement of 1.01% suggested by the NRC, but less than the requirement found in recent experiments at the University of Missouri and Kansas State University. Genotype and environment potentially alter the maintenance requirement and change the absolute amount of lysine needed for maximum growth. The pigs used in the University of Missouri and Kansas State University trials were PIC, whereas our study was conducted with Genetiporc pigs. This may explain the difference in the TID lysine requirement suggested by the previous studies (PIC) compared with that in our experiment (Genetiporc). In Exp. 2, the lysine concentration was set at 1.1% TID lysine, and was less than the actual requirement (1.4%) that had been previously determined for pigs in these facilities.

The arrangement of Exp. 1 as a combination trial that determined both the lysine and threonine requirements simultaneously allowed the use of a regression approach in the establishment of a TID threonine-to-lysine ratio. In this approach, ADG and F/G values are plotted as the dependent variables on the x axis with the TID lysine and threonine concentrations on the Y-axis (Figures 1 to 4). A trend line is fit through the data to develop a regression equation to predict the TID lysine and threonine requirement; the trend line can be used to estimate the TID threonine-to-lysine ratio. The values for ADG and F/G from the individual lysine and threonine trials must overlap to allow this approach to work. In our trial, ADG is shown to be maximized at a threonine-to-lysine ratio approaching 70% (Table 5). But almost 97% of the maximum response can be achieved using a TID threonine-to-lysine ratio of approximately 64%. Feed efficiency was optimized at a TID threonine-to-lysine ratio of 66% (Table 5). This analysis further verifies a TID threonine-to-lysine ratio of approximately 66%, as suggested by our performance and blood data in Exp. 1 for the 24- to 44-lb pig.

The PUN and individual amino acid concentrations in plasma are consistent with the typical responses expected when titrating limiting amino acids. When the concentration of the test amino acid is less than the require-

ment, PUN values are high as a result of oxidation of plasma amino acids because protein synthesis is limited by the test amino acid. As the concentration of the test amino acid approaches and equals the requirement, PUN values decrease as other amino acids are incorporated into protein synthesis, and are no longer oxidized. But the concentration of the test amino acid in plasma increases as it is no longer limiting and begins to exceed the requirement for protein synthesis.

From the lysine and threonine estimates suggested by the NRC, a TID threonine-to-lysine ratio of 62% (total threonine-to-lysine ratio of 64%) is implicated. When compared on a ratio basis, the 64 to 66% TID threonine-to-lysine ratio suggested by our trials is slightly greater than the 62% suggested by the NRC.

Table 1. Composition of Diets (As-fed Basis)

Ingredient, %	Experiment 1[a]	Experiment 2[b]
Corn	65.96	71.13
Soybean meal, 46.5% CP	27.65	23.60
Soy oil	1.50	---
Choice white grease	---	1.00
Monocalcium phosphate, 21% P	1.55	---
Dicalcium phosphate, 18.5% P	---	1.40
Limestone	0.95	0.75
Salt	0.35	0.35
Vitamin/trace mineral premix	0.40	0.30
Medication	0.50	0.70
L-lysine HCl	0.53	0.40
L-threonine	0.25	0.23
DL-methionine	0.23	0.14
L-valine	0.08	---
Tryptophan	0.03	---
L-isoleucine	0.02	---
Total	100.0	100.0
True-ileal-digestible lysine, %	1.30	1.10
True-ileal-digestible threonine, %	0.85	0.77
Isoleucine:lysine ratio, %	55%	58%
Leucine:lysine ratio, %	116%	129%
Methionine:lysine ratio, %	38%	34%
Met & Cys:lysine ratio, %	60%	60%
Threonine:lysine ratio, %	66%	71%
Tryptophan:lysine ratio, %	17%	16%
Valine:lysine ratio, %	65%	67%
ME, kcal/kg	3,355	3,344
Crude protein, %	18.5	17.0
Ca, %	0.76	0.68
P, %	0.70	0.62
Available P, %	0.40	0.32
TID lysine:calorie ratio, g/mcal	3.87	3.29

[a]In Exp. 1, cornstarch replaced L-lysine or L-threonine in the control diet to provide 0.9, 1.0, 1.1, 1.2, or 1.3% TID lysine and 0.60, 0.66, 0.73, 0.79, or 0.85% TID threonine for the dietary treatments. Analyzed values for total lysine were 1.06, 1.16, 1.25, 1.32, and 1.39 %, respectively, in the first part of the trial, and analyzed total threonine values were 0.78, 0.80, 0.88, 0.91, and 0.96%, respectively for the second part of the trial. The diets containing 0.9% TID lysine with 0.60% TID threonine, 1.3% TID lysine with 0.60% TID threonine, and 1.3% TID lysine with 0.85% TID threonine were blended to form all other diets.

[b]In Exp. 2, analyzed total threonine values were 0.68, 0.70, 0.66, 0.77, and 0.83%. The negative- and positive-control diets containing 0.55 and 0.77% TID threonine, respectively, were blended to form the diets with 0.60, 0.66, and 0.72% TID threonine.

Table 2. Effects of Increasing True-ileal-digestible (TID) Lysine and Threonine on Growth Performance of 24- to 44-lb Nursery Pigs (Exp. 1)[a]

	TID Lysine, %					TID Threonine, %					SED	Probability (P<)			
												Lysine		Threonine	
Item	0.9	1.0	1.1	1.2	1.3[b]	0.60	0.66	0.73	0.79	0.85[b]		Linear	Quadratic	Linear	Quadratic
ADG, lb	1.17	1.19	1.29	1.32	1.28	1.24	1.26	1.27	1.33	1.28	0.04	0.01	0.02	0.03	0.26
ADFI, lb	2.02	1.92	2.02	2.03	1.98	2.04	1.98	1.98	2.03	1.98	0.08	0.81	1.00	0.45	0.64
F/G	1.72	1.61	1.56	1.54	1.54	1.64	1.57	1.56	1.53	1.54	0.02	0.01	0.01	0.01	0.04

[a] A total of 360 pigs (average wt of 23.6 lb), with five pigs per pen and eight pens per treatment, with experimental diets fed for 17 d.
[b]The diets containing 1.3% TID lysine and 0.85% TID threonine were combined as one treatment, giving a total of eight replications.

Table 3. Effects of Increasing True-ileal-digestible (TID) Lysine and Threonine on Plasma Amino Acid Profile and Plasma Urea Nitrogen of the 22- to 44-lb Nursery Pig (Exp. 1)[a]

	TID Lysine, %					TID Threonine, %					SED	Probability (P<)			
												Lysine		Threonine	
Amino acid, µm/L	0.9	1.0	1.1	1.2	1.3	0.60	0.66	0.73	0.79	0.85		Linear	Quadratic	Linear	Quadratic
Lysine	58	85	90	143	154	212	170	179	209	154	15.78	0.01	0.78	0.38	0.64
Threonine	230	223	175	223	206	62	70	131	243	206	16.85	0.38	0.23	0.01	0.01
Histidine	65	48	42	35	34	40	31	34	42	34	6.96	0.01	0.22	0.40	0.77
Isoleucine	103	103	92	94	88	86	86	85	97	88	3.41	0.01	0.93	0.02	0.16
Leucine	178	201	175	176	169	176	171	176	192	169	8.30	0.11	0.30	0.26	0.18
Methionine	27	30	35	33	49	37	27	34	44	49	7.41	0.05	0.49	0.08	0.81
Phenylalanine	88	83	75	71	71	75	61	71	77	71	3.85	0.01	0.40	0.10	0.35
Tryptophan	47	47	42	46	43	43	41	42	48	43	2.85	0.27	0.80	0.12	0.33
Tyrosine	97	105	91	100	87	94	91	101	108	87	6.63	0.26	0.45	0.63	0.05
Valine	208	195	170	154	166	179	154	164	190	166	10.21	0.01	0.14	0.05	0.44
PUN, mg/dL	21.9	15.51	15.46	8.74	13.92	15.52	8.32	9.87	12.63	13.92	1.75	0.01	0.01	0.04	0.19

[a]Values represent the mean of eight replications (pens) of individual samples from two pigs per pen for plasma urea nitrogen concentration and pooled samples from two pigs per pen for plasma amino acid concentrations. Blood samples were collected on d 12, after 3 h feed withdrawal.

Table 4. Effect of Increasing True-ileal-digestible (TID) Threonine on Growth Performance of 24- to 45-lb Nursery Pigs (Exp. 2)[ab]

	TID Threonine, %						Probability (P<)	
Item	0.55	0.60	0.66	0.72	0.77	SED	Linear	Quadratic
ADG, lb	0.93	0.99	0.99	1.01	1.00	0.021	0.001	0.06
ADFI, lb	1.71	1.76	1.69	1.72	1.71	0.038	0.53	0.82
F/G	1.84	1.79	1.72	1.70	1.71	0.021	0.001	0.01
Avg weight, lb								
d 42	43.7	45.0	44.9	45.5	45.2	0.46	0.002	0.06

[a]A total of 1,440 pigs (average wt of 24.0 lb), with 48 pigs per experimental unit and six replications per treatment, with experimental diets fed for 21 d.
[b]Diets contained 1.1% TID lysine to give TID threonine-to-lysine ratios of 50, 55, 60, 65, and 70%.

Table 5. Estimation of True-ileal-digestible (TID) Lysine and Threonine Requirements, and Threonine-to-lysine Ratio, Based on Regression Analysis for Different Levels of Pig Performance (Exp. 1)[a]

Item	Lysine, %	Threonine, %	Threonine:Lysine	% of Maximum
ADG, lb[b]				
1.24	1.164	0.571	49.0	93.9
1.27	1.207	0.748	61.9	96.2
1.30	1.204	0.824	68.4	98.5
1.32	1.177	0.818	69.5	100.0
F/G[c]				
1.64	0.915	0.599	65.5	93.7
1.60	1.001	0.610	61.0	96.0
1.56	1.140	0.707	62.1	98.5
1.54	1.248	0.807	64.7	100.0

[a]The range of ADG and F/G values as observed in Exp. 1 were plotted against TID lysine and threonine concentrations used in the experiment to determine TID lysine and threonine concentrations necessary to achieve a given ADG or F/G, and hence, a TID threonine-to-lysine ratio.
[b]Regression equations of y = -25.677x2 + 65.891x - 41.06 and y = -55.921x2 + 146.25x - 94.795 were used to determine lysine and threonine requirements, respectively, for the range of ADG values (Figures 1 and 2).
[c]Regression equations of y = 16.396x2 - 55.278x + 47.472 and y = 26.919x2 - 87.494x + 71.688 were used to determine lysine and threonine requirements, respectively, for the range of F/G values (Figures 3 and 4).

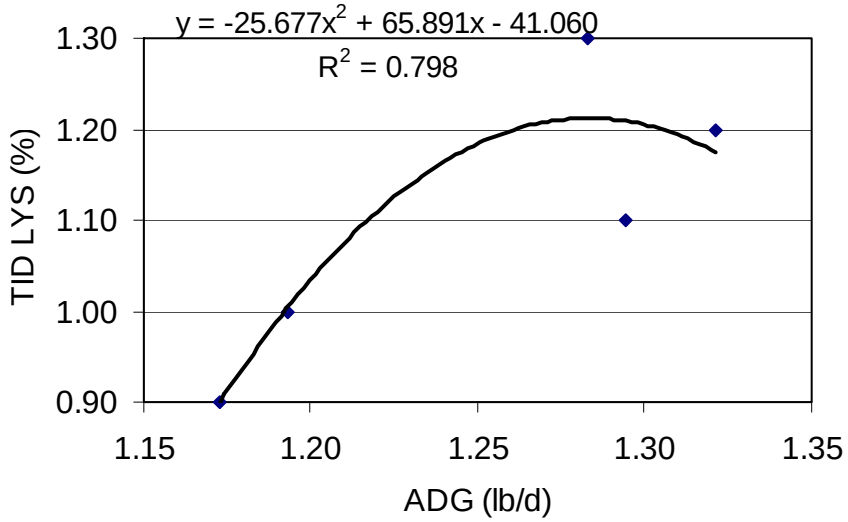

Figure 1. Effect of Increasing True-ileal-digestible Lysine on Average Daily Gain of Nursery Pigs (Exp. 1). A total of 360 pigs (average wt of 23.8 lb), with five pigs per pen and eight pens per treatment, with experimental diets fed for 17 d. True-ileal-digestible lysine concentrations were 0.9, 1.0, 1.1, 1.2, and 1.3%. The ADG values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain average daily gain.

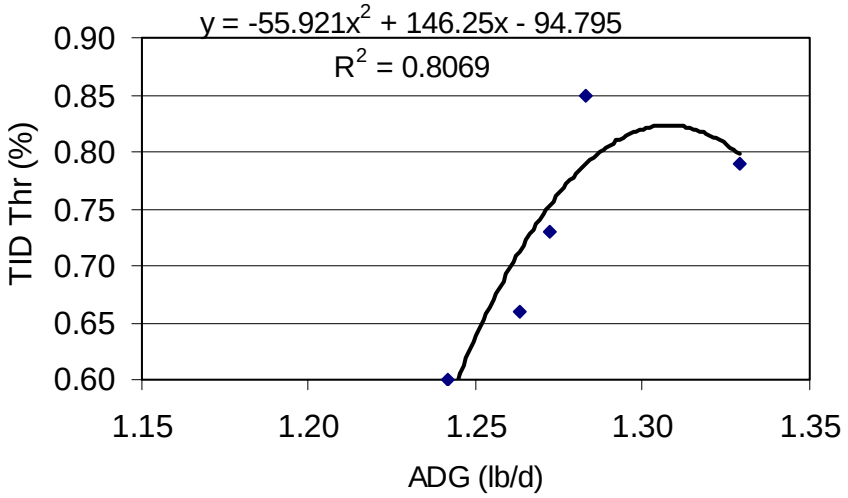

Figure 2. Effect of Increasing True-ileal-digestible Threonine on Average Daily Gain of Nursery Pigs (Exp. 1). A total of 360 pigs (average wt of 23.8 lb), with five pigs per pen and eight pens per treatment, with experimental diets fed for 17 d. True-ileal-digestible threonine concentrations were 0.60, 0.66, 0.73, 0.79, and 0.85%. The ADG values were plotted against TID threonine concentrations used in the experiment to determine the threonine concentration necessary to achieve a certain average daily gain.

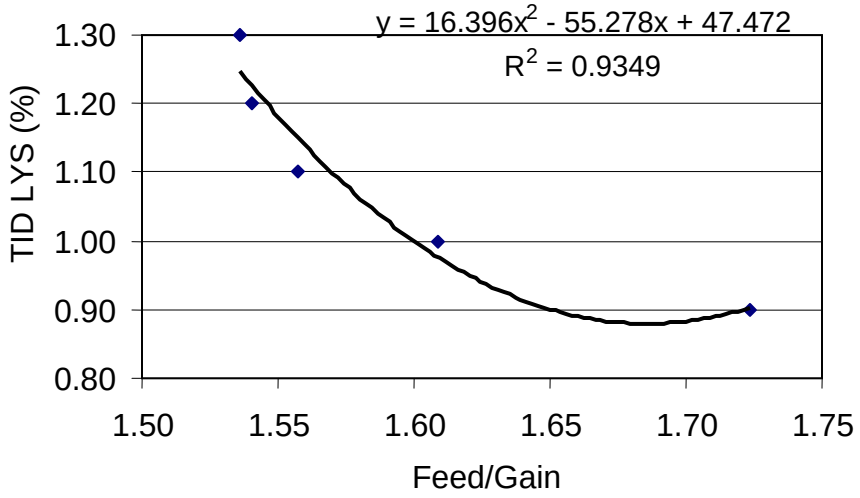

Figure 3. Effect of Increasing True-ileal-digestible Lysine on Feed Efficiency of Nursery Pigs (Exp. 1). A total of 360 pigs (average wt of 23.8 lb), with five pigs per pen and eight pens per treatment, with experimental diets fed for 17 d. True-ileal-digestible lysine concentrations were 0.9, 1.0, 1.1, 1.2, and 1.3%. The F/G values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain F/G ratio.

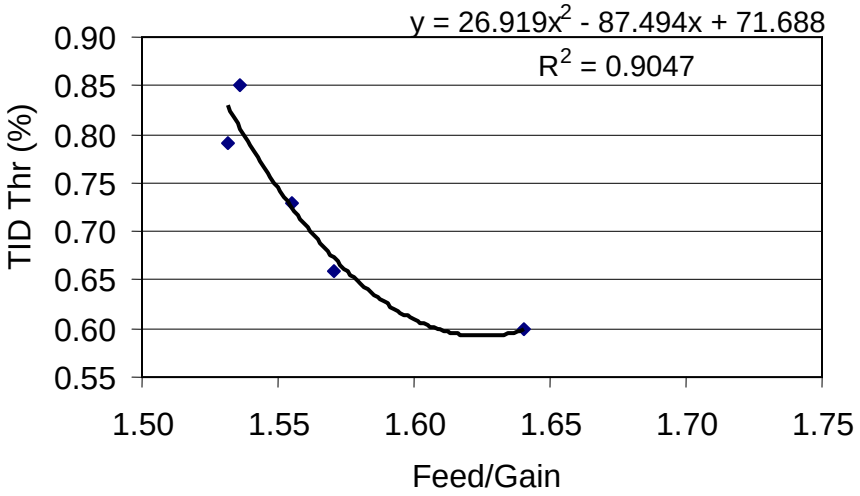

Figure 4. Effect of Increasing True ileal digestible Threonine on Feed Efficiency of Nursery Pigs (Exp. 1). A total of 360 pigs (average wt of 23.8 lb), with five pigs per pen and eight pens per treatment, with experimental diets fed for 17 d. True-ileal-digestible threonine concentrations were 0.60, 0.66, 0.73, 0.79, and 0.85%. The F/G values were plotted against TID concentrations used in the experiment to determine the threonine concentration necessary to achieve a certain F/G ratio**.**

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THE OPTIMAL TRUE-ILEAL-DIGESTIBLE LYSINE AND THREONINE REQUIREMENTS FOR GROWING-FINISHING PIGS FROM 80 TO 130 AND 170 TO 230 POUNDS

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Summary

A total of 4388 pigs (PIC 337 × C22; Exp. 1: 1070 gilts, initially 79 lb BW; Exp. 2: 3318 pigs, initially 170 lb BW) were used in 28-d growth assays to examine both the true-ileal-digestible (TID) lysine and threonine requirements, and then determine the appropriate TID threonine-to-lysine ratio in growing-finishing pigs from 80 to 130 lb and 170 to 230 lb. In Exp. 1, four TID lysine (0.71. 0.81, 0.91, and 1.01%) and five TID threonine (0.50, 0.56, 0.62, 0.68 and 0.74%) concentrations were evaluated. In Exp. 2, four TID lysine (0.56, 0.64, 0.72, and 0.80%), and five TID threonine (0.43, 0.48, 0.53, 0.58 and 0.63%) concentrations were evaluated. The diet with the highest concentration of lysine and second-highest concentration of threonine served as a positive control in both studies, and this diet was combined as one treatment to give a total of nine treatments in each study. Other amino acids were formulated to meet, or exceed, requirement estimates to ensure that lysine and threonine were the only limiting amino acids. In Exp. 1, increasing TID lysine tended to increase ADG (quadratic, P<0.06), with the greatest response occurring from 0.71 to 0.81%. Increasing TID lysine also quadratically increased ADFI (P<0.03) up to 0.81% TID lysine, and linearly improved feed efficiency (F/G; P<0.01), up to 1.01% TID lysine. Increasing TID threonine did not affect ADG (P>0.69) or ADFI (P>0.29), but improved F/G (linear, P<0.05), with the maximum response occurring at 0.68% TID threonine. Values of 1.01% TID lysine and 0.68% TID threonine in Exp. 1 suggest an optimal TID threonine-to-lysine ratio of 67% for F/G. In Exp. 2, a treatment × gender interaction was observed for F/G (P<0.02). This was because gilts had a greater response to increasing TID lysine, whereas barrows had a greater response to increasing TID threonine. In Exp. 2, increasing TID lysine improved ADG (linear, P<0.05) in gilts and barrows (P<0.07), and improved F/G (linear, P<0.01) in gilts, as the TID lysine concentration increased to 0.72%. Increasing TID threonine improved ADG and F/G (linear, P<0.04) in barrows and increased ADG and ADFI (linear, P<0.06) in gilts as the threonine concentration increased to 0.48%. Values of 0.72% TID lysine and 0.48% TID threonine in Exp. 2 suggest an optimum TID threonine-to-lysine ratio of 67%. The practical TID threonine-to-lysine ratio suggested by this study for pigs from 80 to 130 lb and from 170 to 230 lb is 67%. Further research is needed to verify these results and evaluate the economics of feeding higher threonine concentrations.

(Key Words: Growing Pigs, Lysine, Pigs, Threonine.)

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Introduction

The National Research Council (NRC) suggests a dietary TID threonine concentration of 0.43% for a 80- to 130-lb pig and 0.34% for a 170- to 230-lb pig. The NRC also estimates dietary TID lysine concentrations of 0.66% and 0.52% for 80- to 130-lb and 170- to 230-lb pigs, respectively. This calculates to TID threonine-to-lysine ratios of 65% and 67% over the respective weight ranges. Lysine is considered the first-limiting amino acid, with threonine or methionine being second-limiting in corn-soybean meal diets. As increasing inclusion rates of crystalline amino acids become more cost effective, it is essential to understand the proper ratios, relative to lysine, required to promote optimal growth performance during different growing periods. When adding more than 0.15% L-lysine HCl to the diet, supplementation of both methionine and threonine also will be needed. The objective of this experiment was to determine the optimal ratio of threonine to lysine in diets to maximize growth performance of pigs in the late-growing and early-finishing phases. To achieve our objective, two trials were run simultaneously within each experiment, to determine a lysine and threonine requirement, and then to determine a TID threonine-to-lysine ratio from each experiment.

Procedures

General

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. Both trials were conducted at a commercial swine research facility in southwestern Minnesota. The facility is made up of four individual barns, each 41 × 250 ft, with 48, 10 × 18 ft, totally slatted concrete pens. Each pen was equipped with a four-hole dry self-feeder (Staco, Schaefferstown, PA) and a one-cup waterer to allow ad libitum access to feed and water. The finishing facilities were double curtain-sided, deep-pit barns that operated on manual ventilation during the summer and on automatic ventilation during the winter. Pigs and feeders were weighed on d 0, 14, and 28 to determine the response criteria of ADG, ADFI, and F/G. From previous lysine-titration studies conducted in these same facilities, we estimated the pigs' actual lysine requirement over their respective weight ranges and used this as the third-highest lysine concentration in both experiments.

Experiment 1

A total of 1070 gilts (PIC 337 × C22, initially 79 lb BW) were blocked by weight in a 28-d growth assay. They were randomly allotted to one of eight dietary treatments in a randomized complete-block design, with the diet containing the highest lysine and second-highest threonine concentrations combined as one treatment to give a total of nine treatments. Each pen contained approximately 27 ± 1 pigs per pen and five replicates (pens) per treatment, with the number of pigs balanced across treatments. Experimental diets were based on corn-soybean meal (Table 1) and were fed for 28 d in meal form. The positive-control diet was formulated with the highest lysine (1.01%) and second-highest threonine (0.68%) concentrations. In formulating the remaining diets, either L-lysine HCl or L-threonine replaced corn. L-lysine HCl was added to provide 0.71, 0.81, 0.91, or 1.01% TID lysine. The diets for the threonine trial were set at 1.01% TID lysine, and crystalline L-threonine was added to obtain 0.50, 0.56, 0.62, 0.68, or 0.74% TID threonine. The values used in diet formulation and TID values were based on those published by the NRC.

Experiment 2

A total of 3318 pigs (PIC 337 × C22, initially 170 lb BW) were blocked by weight and sex in a 28-d growth assay. They were randomly allotted to one of eight dietary treatments in a randomized incomplete-block design. Each pen contained approximately 24 ± 2 pigs per pen. Three barns were used, two with four complete replications (two barrow

and two gilt), and two incomplete blocks. The 0.56%-TID-lysine treatment was deleted from the middle block of barrows in one barn, whereas the 0.64%-TID-lysine treatment was deleted from the middle block of barrows in the other barn because of a shortage of pigs. The 0.53%-TID-threonine treatment was deleted from the middle block of gilts in one barn, and the 0.64%-TID-lysine and 0.63%-TID-threonine treatments from the middle block of gilts in the other barn. The third barn contained five complete replications of gilts. Thus, there were 14 to 16 replications of each treatment. Diets were based on corn-soybean meal (Table 2) and were fed in meal form for 28 d. The positive-control diet was formulated with the highest TID lysine (0.80%) and second-highest TID threonine (0.58%) concentration. In formulating the remaining diets, either L-lysine HCl or L-threonine replaced corn. L-lysine HCl was added to provide 0.56, 0.64, 0.72, or 0.80% TID lysine. The diets for the threonine trial were set at 0.80% TID lysine, and crystalline L-threonine was added to obtain 0.44, 0.48, 0.53, 0.58, or 0.63% TID threonine. The values used in diet formulation were based on those published by the NRC.

Statistical Analysis

Data were analyzed as a randomized complete-block design by using the PROC MIXED procedure of SAS, with pen as the experimental unit, in Exp. 1, and as a randomized incomplete-block design in Exp. 2. Linear and quadratic polynomial contrasts were performed to determine the effects of increasing dietary lysine and threonine in both experiments.

Results and Discussion

Experiment 1

Increasing dietary TID lysine increased ADG (linear, $P<0.04$; quadratic, $P<0.06$; Table 2), with the greatest response occurring from 0.71 to 0.81% TID lysine. Increasing TID lysine increased ADFI (quadratic, $P<0.03$), with pigs fed 0.81% TID lysine having the greatest intake. Increasing TID lysine also improved F/G (linear, $P<0.01$), with the maximum response for F/G occurring at 1.01%.

Increasing dietary TID threonine did not affect ADG ($P>0.69$; Table 3) or ADFI ($P>0.29$), but did improve F/G (linear, $P<0.05$), with the best F/G occurring at 0.68% TID threonine. Using 1.01% TID lysine for F/G, this results in a TID threonine-to-lysine ratio of 67%.

Experiment 2

A treatment × gender interaction was observed for F/G ($P<0.02$; Table 4). This was because TID lysine improved F/G in gilts, whereas TID threonine improved F/G in barrows. No other interactions were observed ($P>0.10$).

Increasing TID lysine increased ADG (linear, $P<0.01$; Table 4), tended to increase ADFI (linear, $P<0.07$), and improved F/G (linear, $P<0.04$). In gilts, increasing TID lysine increased ADG (linear, $P<0.05$; Table 4) and F/G (linear, $P<0.01$), but did not affect ADFI ($P>0.49$). In barrows, increasing TID lysine tended to increase ADG (linear, $P<0.07$; Table 4) and increased ADFI (linear, $P<0.01$), but had no affect on F/G ($P>0.80$). Although the response to lysine was linear, ADG was maximized and F/G was minimized at 0.72% TID lysine in barrows and at 0.80% in gilts.

Increasing TID threonine improved ADG (linear, $P<0.01$; Table 5) and F/G (linear, $P<0.01$), but did not affect ADFI ($P>0.20$). Increasing TID threonine increased ADG (linear, $P<0.05$; Table 5) for both barrows and gilts. Increasing TID threonine tended to increase ADFI (linear, $P<0.06$) in gilts, but did not affect ADFI in barrows ($P>0.84$). Increasing TID threonine improved F/G (linear, $P<0.01$; quadratic, $P<0.08$) in barrows, but did not affect F/G in gilts ($P>0.38$). Although the

response to TID threonine was linear, the greatest response to threonine occurred by increasing TID threonine from 0.43 to 0.48%. If 0.48% TID threonine and 0.72% TID lysine are used as the requirements, a TID threonine-to-lysine ratio of 67% seems optimal according to results of Exp. 2.

To further verify our threonine-to-lysine ratios, as suggested by the performance data, the range of F/G values obtained in Exp. 1 and the ADG and F/G values obtained in Exp. 2 were used in regression analysis to predict the TID lysine and threonine requirements and, thus, a ratio for different rates of ADG and F/G. Because there was no ADG response to additional threonine in Exp. 1, ADG values could not be used in the regression analysis to determine a threonine-to-lysine ratio for ADG. Figures 1 and 2 show TID lysine and threonine concentrations plotted against F/G values for Exp. 1; Figures 3, 4, 5, and 6 show TID lysine and threonine concentrations plotted against ADG and F/G values for Exp. 2. A trendline was added to each graph, resulting in a regression equation. On the basis of regression equations, a threonine-to-lysine ratio necessary to achieve a given ADG or F/G can be determined. Feed efficiency was maximized at a threonine-to-lysine ratio of 74% in Exp. 1, but more than 96% of the maximal response can be achieved by using a threonine-to-lysine ratio of 60% (Table 6). In Exp. 2, ADG is maximized at 77%, whereas F/G is maximized at 72% (Table 7). In 170- to 230-lb pigs, 95% of the maximal response can be achieved by using a threonine-to-lysine ratio of 70%.

The greater TID lysine requirement found in Exp. 1 is probably due to increased protein-deposition rates of modern genetics and because only gilts were used in this study. The greater threonine requirement found in our studies provides some validity to the proposed greater maintenance requirement for threonine of grow-finish pigs compared with that for nursery pigs and, when expressed as a ratio relative to lysine, is similar to NRC recommendations. Our data suggest that barrows respond more favorably to higher threonine concentrations than gilts do. This is reasonable, considering that barrows decrease in lean deposition rates sooner than gilts and, thus, would have a greater maintenance requirement at a similar body weight. The practical TID threonine-to-lysine ratio suggested by this study for 80- to 130-lb and 170- to 230-lb pigs is 67%, even though a statistical response to higher concentrations of threonine was observed.

Table 1. Diet Composition (Exp. 1 and 2; As-fed Basis)[a]

Item	Exp. 1[bc]	Exp. 2[d]
Ingredient, %		
Corn	74.95	81.06
Soybean meal, 46.5% CP	20.64	14.68
Choice white grease	2.00	2.00
Monocalcium phosphate, 21% P	0.40	0.40
Limestone	0.80	0.80
Salt	0.35	0.35
Vitamin premix with phytase	0.08	0.08
Trace mineral premix	0.10	0.10
L-Lysine HCl	0.38	0.30
DL-Methionine	0.13	0.08
L-Threonine	0.18	0.15
Calculated Values		
Total Lysine %	1.12	0.89
True-ileal-digestible amino acids		
Lysine, %	1.01	0.81
Isoleucine:lysine ratio %	0.59	0.60
Leucine:lysine ratio %	1.34	1.52
Methionine:lysine ratio %	0.35	0.37
Met & Cys:lysine ratio %	0.61	0.65
Threonine:lysine ratio %	0.69	0.72
Tryptophan:lysine ratio %	0.16	0.16
Valine:lysine ratio %	0.68	0.71
ME, kcal/lb	1,565	1,565
CP %	15.97	13.70
Ca %	0.47	0.45
P %	0.44	0.41
Lysine:calorie ratio, g/mcal	3.25	2.58

[a]Diets fed in meal form for 28 d.

[b]Corn replaced L-Lysine HCl to provide additional true-ileal-digestible (TID) lysine treatments (0.71, 0.81, 0.91, and 1.01%); L-threonine and corn were altered to provide additional TID threonine treatments (0.50, 0.56, 0.62, 0.68, and 0.74%).

[c]Analyzed values for diets with 0.71, 0.81, 0.91, and 1.01% TID lysine were 0.83, 0.90, 1.00, and 1.05% total lysine, respectively, and the diets containing 0.50, 0.56, 0.62, 0.68, and 0.74% TID threonine were 0.62, 0.66, 0.68, 0.73, and 0.77% total threonine, respectively.

[d]Corn replaced L-Lysine HCl, resulting in four true-ileal-digestible (TID) lysine treatments (0.56, 0.64, 0.72, and 0.80%), whereas L-threonine and corn were altered to provide the additional TID threonine treatments (0.43, 0.48, 0.53, 0.58, 0.63%).

Table 2. Effects of Increasing True-ileal-digestible (TID) Lysine in 80- to 130-lb Gilts (Exp. 1)[a]

	TID Lysine %					P-value	
Item	0.71	0.81	0.91	1.01[b]	SE	Linear	Quadratic
ADG, lb	1.58	1.76	1.72	1.73	0.060	0.04	0.06
ADFI, lb	3.91	4.12	4.05	3.91	0.105	0.78	0.03
F/G	2.49	2.34	2.36	2.26	0.049	0.01	0.47

[a]Each value is the mean of five replications with 27 ± 1 pigs (PIC 337 × C22, initially 79 lb BW) per pen.
[b]The 1.01% TID lysine treatment is also shown as the 0.68% TID threonine treatment in Table 3.

Table 3. Effects of Increasing True-ileal-digestible (TID) Threonine in 80- to 130-lb Gilts (Exp. 1)[a]

	TID Threonine %						P-value	
Item	0.50	0.56	0.62	0.68	0.74	SE	Linear	Quadratic
ADG, lb	1.69	1.65	1.67	1.73	1.68	0.060	0.69	0.85
ADFI, lb	3.97	3.84	3.84	3.91	3.81	0.105	0.29	0.61
F/G	2.35	2.33	2.30	2.26	2.27	0.049	0.05	0.77

[a]Each value is the mean of five replications with 27 ± 1 pigs (PIC 337 × C22, initially 79 lb BW) per pen.

Table 4. Effects of Increasing True-ileal-digestible (TID) Lysine in 170- to 230-lb Pigs (Exp. 2)[ab]

	TID Lysine %					P-value			
Item	0.56	0.64	0.72	0.80	SE	Linear	Quadratic	Treatment	Treatment*Sex
ADG, lb	1.89	1.90	1.99	1.97	0.038	0.01	0.52	0.01	0.14
Barrows	1.96	1.95	2.11	2.03	0.063	0.07	0.47		
Gilts	1.82	1.86	1.87	1.91	0.044	0.05	0.94		
ADFI, lb	5.74	5.76	5.86	5.86	0.081	0.60	0.10	0.07	0.83
Barrows	5.93	6.01	6.27	6.21	0.134	0.01	0.44		
Gilts	5.54	5.51	5.45	5.51	0.094	0.62	0.49		
F/G	3.06	3.03	2.96	2.98	0.040	0.01	0.02	0.02	0.42
Barrows	3.04	3.08	2.99	3.07	0.066	0.95	0.72		
Gilts	3.07	2.97	2.94	2.90	0.046	0.01	0.38		

[a]Each value is the mean of 14 to 16 replications with 24 ± 2 pigs (PIC 337 × C22, initially 170 lb BW) per pen.
[b]Each barrow or gilt value is the mean of 5 to 11 replications.

Table 5. Effects of Increasing True-ileal-digestible (TID) Threonine in 170- to 230-lb Pigs (Exp. 2)[ab]

	TID Threonine %						P-value	
Item	0.43	0.48	0.53	0.58	0.63	SE	Linear	Quadratic
ADG, lb	1.89	1.95	1.96	1.97	2.00	0.036	0.01	0.49
Barrows	1.92	2.07	2.06	2.03	2.08	0.057	0.04	0.16
Gilts	1.86	1.83	1.87	1.91	1.92	0.044	0.05	0.47
ADFI, lb	5.78	5.76	5.78	5.86	5.85	0.077	0.20	0.75
Barrows	6.15	6.18	6.15	6.21	6.16	0.121	0.87	0.84
Gilts	5.41	5.35	5.41	5.51	5.53	0.094	0.06	0.43
F/G	3.07	2.97	2.95	2.98	2.94	0.038	0.01	0.10
Barrows	3.20	3.00	3.00	3.07	2.98	0.060	0.01	0.08
Gilts	2.93	2.93	2.91	2.90	2.91	0.046	0.38	0.98

[a]Each value is the mean of 15 or 16 replications with 24 ± 2 pigs (PIC 337 × C22, initially 170 lb BW) per pen.
[b]Each barrow or gilt value is the mean of 5 to 11 replications.

Table 6. Estimation of True-ileal-digestible (TID) Lysine and Threonine Requirements, and a Threonine-to-Lysine Ratio, Based on Regression Analysis for Different Levels of Pig Performance (Exp. 1)[a]

Feed Efficiency[b]	Lysine	Threonine	Threonine-to-lysine	% of max
2.26	0.986	0.729	73.9	100
2.30	0.949	0.658	69.4	98.7
2.33	0.912	0.588	64.4	97.4
2.35	0.863	0.494	59.1	96.2

[a]The range of feed-efficiency values were plotted against TID lysine and threonine concentrations in the experiment to determine TID lysine and threonine concentrations necessary to achieve a given feed efficiency, and to calculate a TID threonine-to-lysine ratio (Exp. 1).
[b]Regression equations of y = -1.228230891x + 3.761695692 and y = -2.34693878x + 6.03265306 were used to determine lysine and threonine requirements, respectively, for the range of feed-efficiency values from Figures 1 and 2.

Table 7. Estimation of True-ileal-digestible (TID) Lysine and Threonine Requirements, and a Threonine-to-Lysine Ratio, Based on Regression Analysis for Different Levels of Pig Performance (Exp. 2)[a]

Item	Lysine	Threonine	Threonine-to-lysine	% of max
ADG, lb[b]				
1.99	0.773	0.596	77	100.0
1.95	0.702	0.523	74	98.0
1.90	0.614	0.431	70	95.5
Feed Efficiency[c]				
2.96	0.774	0.556	72	100.0
3.00	0.696	0.509	73	98.7
3.03	0.637	0.474	74	97.7
3.06	0.578	0.439	76	96.7

[a]The range of ADG and feed-efficiency values as observed in Exp. 2 were plotted against TID lysine and threonine concentrations used in the experiment to determine TID lysine and threonine concentrations necessary to achieve a given ADG or feed efficiency, and to calculate a TID threonine-to-lysine ratio (Exp. 2).
[b]Regression equations of y = 4.078431373x -2.898823529 and y = 4.16666667x – 3.16166667 were used to determine lysine and threonine requirements, respectively, for the range of ADG values from Figures 3 and 4.
[c]Regression equations of y = 1.765886288x – 2.741404682 and y = 1.84049080x – 3.06631902 were used to determine lysine and threonine requirements, respectively,
for the range of feed-efficiency values from Figures 5 and 6.

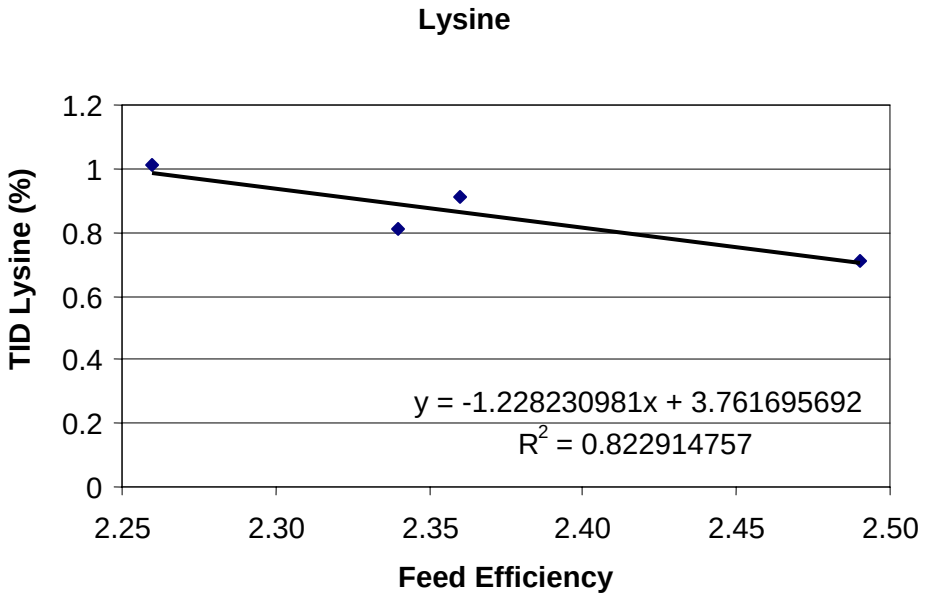

Figure 1. The Effect of Increasing True-ileal-digestible (TID) Lysine on Feed Efficiency (Exp. 1). A total of 1,070 pigs (PIC 337 × C22, initially 79 lb BW) with 27 ± 1 pigs per pen and five pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible lysine concentrations were 0.71, 0.81, 0.91, and 1.01%. The range of F/G values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain F/G.

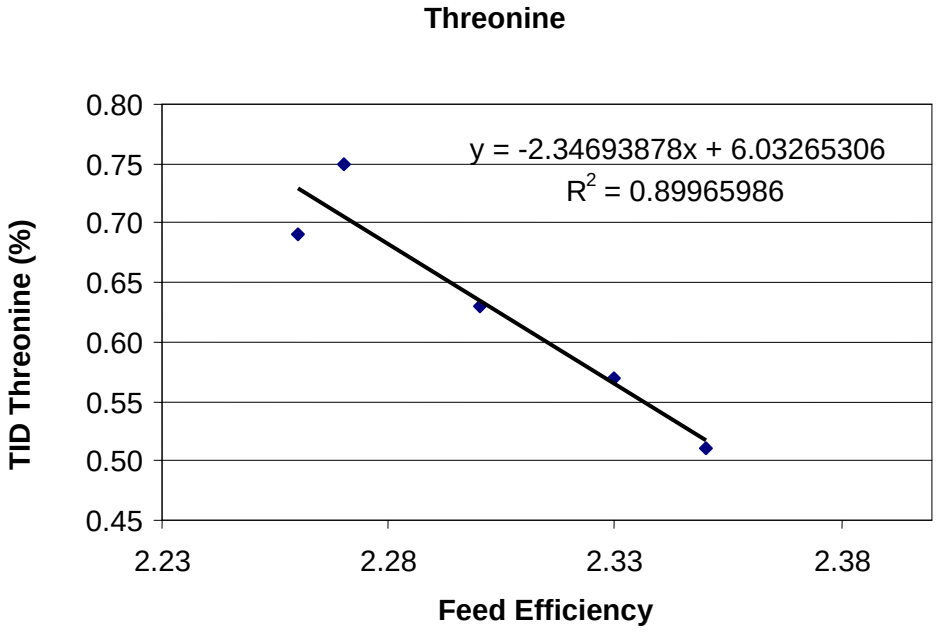

Figure 2. The Effect of Increasing True-ileal-digestible (TID) Threonine on Feed Efficiency (Exp. 1). A total of 1,070 pigs (PIC 337 × C22, initially 79 lb BW) with 27 ± 1 pigs per pen and 5 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible threonine concentrations were 0.50, 0.56, 0.62, 0.68 and 0.74%. The range of F/G values were plotted against TID threonine concentrations used in the experiment to determine the threonine-to-lysine ratio necessary to achieve a certain F/G.

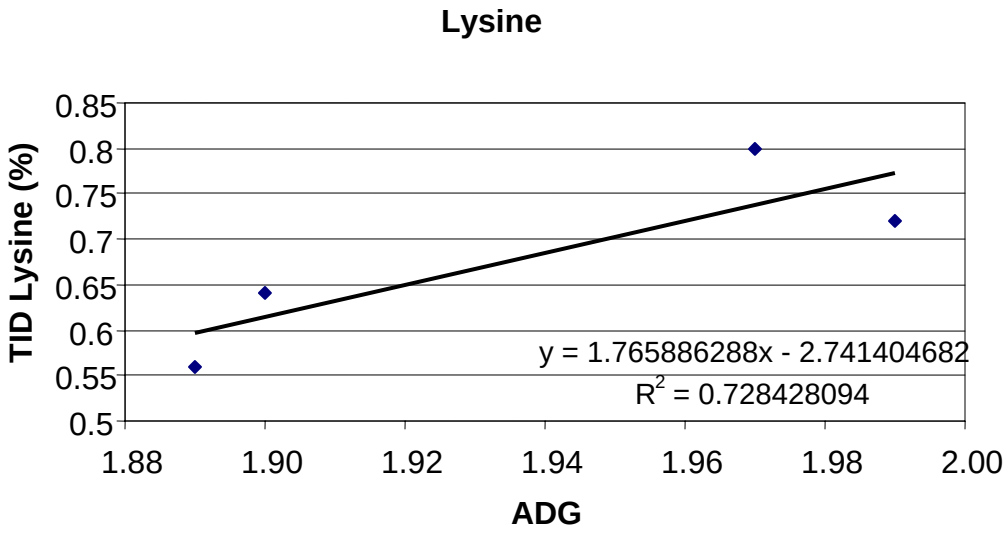

Figure 3. The Effect of Increasing True-ileal-digestible (TID) Lysine on ADG (Exp. 2). A total of 3,318 pigs (PIC 337 × C22, initially 170 lb BW) with 24 ± 2 pigs per pen and 14 to 16 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible lysine concentrations were 0.56, 0.64, 0.72, and 0.80%. The range of ADG values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain ADG.

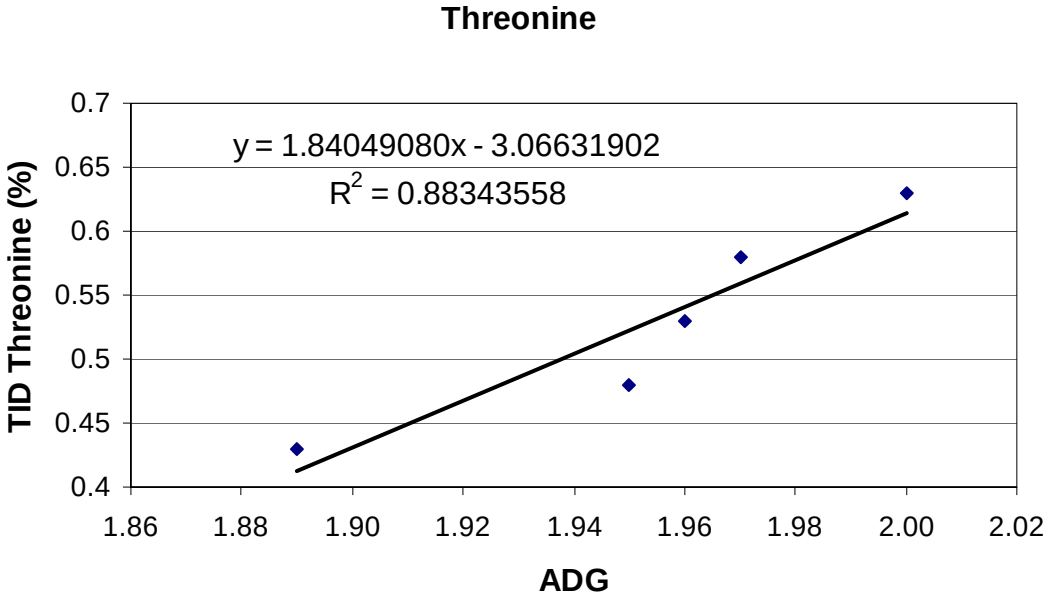

Figure 4. The Effect of Increasing True-ileal-digestible (TID) Threonine on ADG (Exp. 2). A total of 3,318 pigs (PIC 337 × C22, initially 170 lb BW) with 24 ± 2 pigs per pen and 15 or 16 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible threonine concentrations were 0.43, 0.48, 0.53, 0.58 and 0.63%. The range of ADG values were plotted against TID threonine concentrations used in the experiment to determine the threonine-to-lysine ratio necessary to achieve a certain ADG.

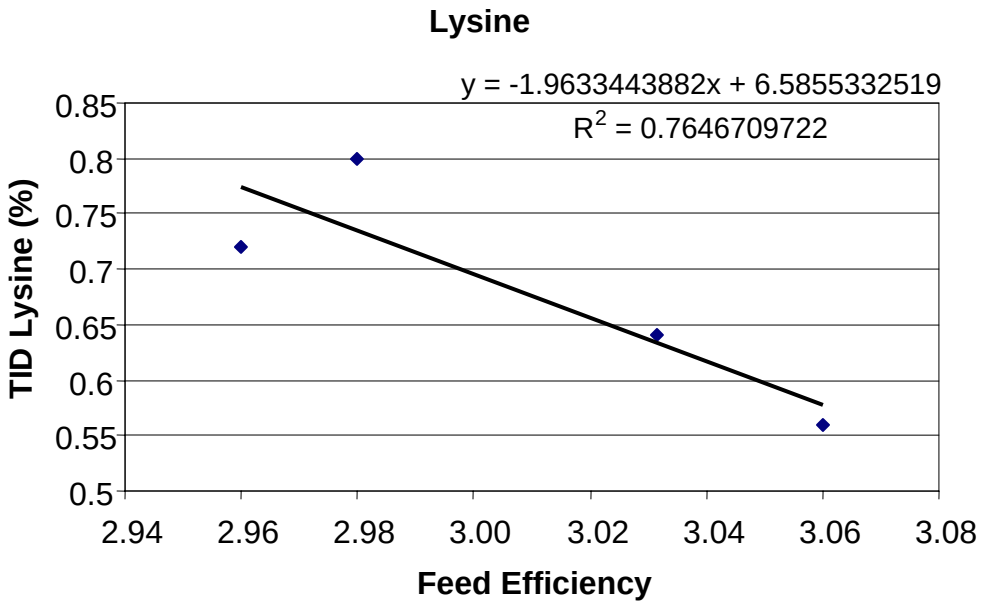

Figure 5. The Effect of Increasing True-ileal-digestible (TID) Lysine on F/G (Exp. 2). A total of 3,318 pigs (PIC 337 × C22, initially 170 lb BW) with 24 ± 2 pigs per pen and 14 to 16 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible lysine concentrations were 0.56, 0.64, 0.72, and 0.80%. The range of F/G values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain F/G.

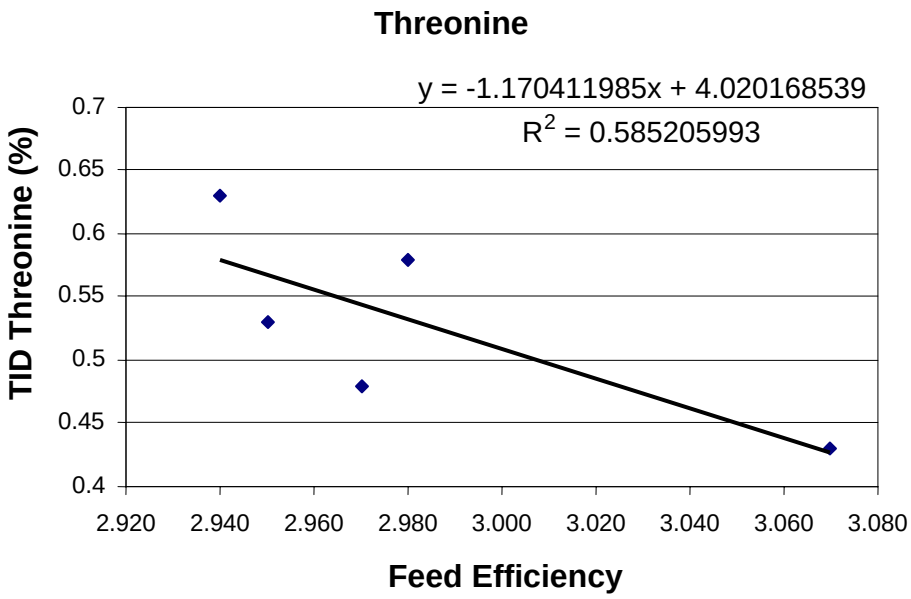

Figure 6. The Effect of Increasing True-ileal-digestible (TID) Threonine on F/G (Exp. 2). A total of 3,318 pigs (PIC 337 × C22, initially 170 lb BW) with 24 ± 2 pigs per pen and 15 or 16 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible threonine concentrations were 0.43, 0.48, 0.53, 0.58 and 0.63%. The range of F/G values were plotted against TID threonine concentrations used in the experiment to determine the threonine-to-lysine ratio necessary to achieve a certain F/G.

EFFECTS OF RATIO OF TOTAL SULFUR AMINO ACID TO LYSINE ON FINISHING-PIG GROWTH PERFORMANCE

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Summary

The objective of this study was to characterize the growth response to total sulfur amino acids (TSAA) and lysine simultaneously to estimate the true-ileal-digestible (TID) TSAA-to-lysine ratio in early finishing pigs. One hundred and twenty-six pigs were used in a 27-d growth study. Pigs (73 to 134 lb) were blocked by sex and weight and were allotted to one of nine dietary treatments with five TID lysine (0.79, 0.87, 0.94, 1.02 and 1.10%) and five TID TSAA (0.53, 0.57, 0.61, 0.66 and 0.70%) concentrations. The highest lysine (1.10%) and TSAA (0.70%) concentrations were combined to form one treatment used in both the lysine and TSAA titrations. In diets evaluating increasing TID lysine, methionine & cysteine ratios were 64 to 66% of lysine; and in diets evaluating increasing TSAA, diets were formulated to 1.10% TID lysine. Increasing TID lysine increased ADG (linear, $P<0.01$) and improved F/G (quadratic, $P<0.10$) from d 0 to 14 and from d 0 to 27. No differences ($P>0.05$) were observed in ADFI. Increasing TSAA had no effect ($P<0.05$) on ADG or F/G, but pigs fed the diet containing 0.70% TSAA had numerically greater ADG than did pigs fed lower rates. As TSAA concentration increased to 0.61%, feed efficiency numerically improved ($P = 0.16$). Using a TID lysine requirement of 1.02% and TID TSAA requirement of 0.61% suggests a TSAA-to-lysine ratio of 60%. The surface response analysis suggests a similar TSAA-to-lysine ratio of 59% for overall F/G.

(Key Words: TSAA, Lysine, Pigs, Finishing Pigs.)

Introduction

Previous research at Kansas State University has demonstrated that titrating the requirement for lysine and an amino acid of interest allows for the accurate determination of the optimum ratio of amino acid to lysine. With the increasing cost competitiveness of synthetic amino acids, there has been interest of supplementing swine diets with synthetic methionine and other amino acids. Research at the University of Missouri has shown that the optimum TID ratio of TSAA to lysine ranges from 58 to 62% to maximize ADG for gilts weighing 100 to 150 lb. Our objective was to determine the ADG and efficiency response to TSAA and lysine to estimate the TID TSAA-to-lysine ratio for barrows and gilts weighing 73 to 134 lb.

Procedures

One hundred and twenty-six pigs were blocked by weight (PIC L326 × C22; initially 73.0 lb) and were allotted to one of nine dietary treatments. There were two pigs per pen, with barrows (initially 74.2 lb) and gilts (initially 71.3 lb) penned separately. There were

[1]Food Animal Health and Management Center.

four replications per treatment for the barrows and three replications per treatment for the gilts. The dietary treatments consisted of five increasing concentrations of TID lysine (0.79, 0.87, 0.94, 1.02, and 1.10%) and five diets with increasing concentrations of TSAA (0.53, 0.57, 0.61, 0.66 and 0.70%). The highest lysine and TSAA were combined (1.10% lysine and 0.70% TSAA) in one diet used for both the lysine and TSAA titrations, for a total of 9 diets and 10 dietary treatments. The TID lysine diets had TSAA ratios of 64 to 66% of lysine, and the TSAA diets were formulated to 1.10% TID lysine. The diet containing .79% lysine and 1.10% lysine and diets containing .70% TID TSAA and 0.53% TID TSAA were blended to form all other diets.

All experimental diets were based on corn-soybean meal (Table 1) and were fed in a meal form throughout the 27-d experiment. Pigs were housed at the K-State Swine Teaching and Research Center and allowed ad libitum access to food and water. All pigs and feeders were weighed on d 14 and 27 to determine ADG, ADFI, and F/G.

Data were analyzed as a randomized complete-block design, with pen as the experimental unit. Pens were blocked on the basis of initial weight. Analysis of variance was performed by using the PROC MIXED procedures of SAS. Linear and quadratic polynomials were evaluated to determine the effects of increasing dietary lysine and TSAA.

Results and Discussion

Overall, increasing TID lysine increased (linear, $P<0.01$) ADG and improved (quadratic, $P<0.03$) F/G (Table 2). Pigs fed 1.02% TID lysine had the greatest ADG and best F/G, compared with ADG and F/G of the pigs fed all other diets.

Increasing TID total TSAA concentration did not significantly improve pig performance, but F/G was improved numerically ($P<0.16$) as TID TSAA increased to .61% of the diet.

Using a TID lysine requirement of 1.02% and TID total sulfur amino acid requirement of 0.61% suggests a TSAA-to-lysine ratio of 60%. The surface-response analysis suggests a similar TSAA-to-lysine ratio of 59% for overall F/G. More research is required to validate our data, but these results indicate that the optimal ratio of TSAA to lysine is approximately 60% for pigs weighing 73 to 133 lb.

Table 1. Diet Composition of True-ileal-digestible (TID) Lysine and TID TSAA[a]

	TID Lysine/TSAA, %		
Ingredient, %	0.79/0.53	1.10/0.70	1.10/0.53
Corn	74.00	73.20	73.38
Soybean meal, 46.5% CP	23.45	23.45	23.45
Monocalcium phosphate, 21%	1.00	1.00	1.00
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15
Lysine HCl	0.00	0.40	0.40
DL-Methionine	0.00	0.18	0.00
L-Threonine	0.00	0.17	0.17
L-Tryptophan	0.00	0.025	0.025
L-Isoleucine	0.00	0.03	0.03
Total	100.00	100.00	100.00
Calculated Analysis			
Lysine, %	0.90	1.21	1.21
Isoleucine:lysine, %	79	61	61
Leucine:lysine, %	177	131	131
Methionine:lysine, %	31	38	23
Met & Cys:lysine, %	66	64	49
Threonine:lysine, %	72	67	67
Tryptophan:lysine, %	22	18	18
Valine:lysine, %	91	67	67
ME, kcal/lb	1,508	1,511	1,510
Protein, %	17.2	17.1	17.1
Ca, %	0.63	0.63	0.63
P, %	0.58	0.58	0.58
Available P, %	0.28	0.28	0.28
Lysine:calorie ratio, g/mcal	2.71	3.64	3.64

[a]The diets containing 0.79% TID lysine and 1.10% TID lysine were blended to form the intermediate diets containing 0.87, 0.94 and 1.02% TID lysine. In addition, the diets containing 0.53% TID TSAA and 0.70% TID TSAA were blended to form the intermediate diets containing 0.57, 0.61 and 0.66% TID TSAA.

Table 2. Effect of Increasing True-ileal-digestible (TID) Lysine in 73.0 to 133.9 lb Pigs[a]

	TID Lysine, %						P-value	
Item	0.79	0.87	0.94	1.02	1.10	SE	Linear	Quadratic
Day 0 to 14								
ADG, lb	2.01	2.08	2.05	2.34	2.30	0.104	0.0009	0.67
ADFI, lb	4.18	4.15	3.94	4.15	4.30	0.152	0.48	0.06
F/G	2.09	2.00	1.93	1.78	1.87	0.066	<0.0001	0.10
Day 14 to 27								
ADG, lb	2.18	2.29	2.36	2.37	2.35	0.101	0.06	0.22
ADFI, lb	5.09	5.13	5.02	5.06	5.23	0.238	0.70	0.50
F/G	2.35	2.26	2.12	2.13	2.24	0.115	0.18	0.07
Day 0 to 27								
ADG, lb	2.09	2.18	2.20	2.36	2.33	0.082	0.0011	0.65
ADFI, lb	4.62	4.62	4.46	4.58	4.75	0.172	0.57	0.19
F/G	2.21	2.12	2.03	1.94	2.05	0.066	0.0016	0.03

[a]Each value is the mean of seven replications with 2 pigs (PIC L326 × C22, initially 73.0 lb) per pen.

Table 3. Effect of Increasing True-ileal-digestible (TID) TSAA in 73.0 to 133.9 lb Pigs[a]

	TID TSAA, %						P-value	
Item	0.53	0.57	0.61	0.66	0.70	SE	Linear	Quadratic
Day 0 to 14								
ADG, lb	2.18	2.22	2.13	2.17	2.30	0.104	0.43	0.27
ADFI, lb	4.22	4.31	3.97	4.24	4.30	0.152	0.80	0.19
F/G	1.95	1.94	1.87	1.94	1.87	0.066	0.36	0.91
Day 14 to 27								
ADG, lb	2.22	2.29	2.36	2.32	2.35	0.101	0.23	0.53
ADFI, lb	5.18	5.21	5.10	4.96	5.23	0.238	0.81	0.48
F/G	2.33	2.27	2.21	2.15	2.24	0.115	0.28	0.32
Day 0 to 27								
ADG, lb	2.20	2.25	2.24	2.24	2.33	0.082	0.22	0.73
ADFI, lb	4.68	4.74	4.52	4.58	4.75	0.172	0.96	0.29
F/G	2.13	2.10	2.03	2.04	2.05	0.066	0.16	0.33

[a]Each value is the mean of seven replications, with 2 pigs (PIC L326 × C22, initially 73.0 lb) per pen.

Swine Day 2004

THE OPTIMAL TRUE-ILEAL-DIGESTIBLE LYSINE AND TOTAL SULFUR AMINO ACID REQUIREMENT FOR NURSERY PIGS BETWEEN 20 AND 50 LB[1]

J. D. Schneider, M. D. Tokach, S. S. Dritz[2], R. D. Goodband, J. L. Nelssen, and J. M. DeRouchey

Summary

An experiment was conducted with 360 pigs (PIC, avg BW = 22.7 lb) to determine the appropriate true-ileal-digestible (TID) lysine and total sulfur amino acid (TSAA) requirement of nursery pigs, and consequently to determine the optimal TSAA-to-lysine ratio. This trial was organized as a combination of two simultaneous experiments, with one set of diets consisting of five treatments with increasing TID lysine (0.9, 1.0, 1.1, 1.2, and 1.3%) and the second set of diets consisting of five treatments with increasing TID TSAA (0.56, 0.62, 0.68, 0.74, and 0.81%). The highest concentrations of both lysine and TSAA (1.3% and 0.81%, respectively) were combined as one diet and used in both the lysine and TSAA titrations, to give a total of 10 treatments. Pigs were randomly allotted to eight replications with five pigs per pen, on the basis of BW. Average daily gain increased (linear, $P<0.01$), but ADFI decreased (linear, $P<0.06$) with increasing TID lysine. Increasing TID lysine also improved (linear, $P<0.01$; and quadratic $P<0.05$) F/G. Increasing TID TSAA from 0.56 to 0.81% increased (linear, $P<0.02$) ADG and improved (linear, $P<0.01$) F/G. The arrangement of treatments in this experiment determined both the lysine and TSAA requirements simultaneously, which allowed the use of a regression approach in the establishment of a TID TSAA-to-lysine ratio. In this approach, ADG and F/G values are plotted as the dependent variables on the X axis and the TID lysine and TSAA concentrations are plotted on the Y axis. A trend line is fit through the data to develop a regression equation to predict the TID lysine and TSAA requirements, which can be used to estimate the TID TSAA-to-lysine ratio. The values for ADG and F/G from the individual lysine and TSAA trials must overlap to allow this approach to work. Regression analysis of the response surface resulted in an estimated TID TSAA-to-lysine ratio range of 55 to 61% for ADG and 57 to 61% for F/G.

(Key Words: Lysine, TSAA, Nursery Pigs, Pigs.)

Introduction

In practical corn-soybean meal diets, total sulfur amino acid (TSAA) concentrations are adequate for optimal swine growth. A recent fluctuation in soybean meal price has increased the use of synthetic amino acids in most diets. Coupled with this is the growing acceptance of the concept that estimates requirements of individual amino acids expressed relative to lysine. Therefore, it is essential to accurately define ratios of other amino acids to lysine.

[1]The authors thank Novus Int. for providing the Alimet® and other crystalline amino acids used in this study.

[2]Food Animal Health and Management Center.

The TSAA requirements for 20- to 50-lb pigs have recently been estimated to be .58%, with a range from .31 to .81%. Continued improvements in lean growth potential may give the pig the ability to deposit a greater amount of protein, which, in turn, may alter their requirements for certain amino acids.

A frequent limitation of experiments with amino acid ratios is determining the actual lysine requirement of the pig. Most studies calculate a ratio on the basis of the lysine concentrations used in the experimental diets; others may estimate lysine requirements from previous studies or National Research Council estimates to extrapolate a ratio. But certain drawbacks may exist for these methods. The former may create more variation of the estimate for lysine requirement if the lysine concentrations used differ too widely from the actual requirement. In the latter method, the optimal amino acid estimate derived in a titration study, by definition, would be related to the lysine rate used in that particular study and not to a predetermined lysine requirement from earlier research.

The objective of these experiments was to concurrently determine the optimal dietary lysine and TSAA requirements, and hence, obtain the appropriate TSAA-to-lysine ratio for maximum growth performance in the nursery pig.

Procedures

Three hundred and sixty pigs were blocked by weight (initially 22.66 lb) and were allotted to one of the nine dietary treatments. There were five pigs per pen and eight replicate pens per treatment. This trial was organized as a combination of two separate experiments, with one set of diets consisting of five treatments with increasing TID lysine (0.9, 1.0, 1.1, 1.2, and 1.3%); other crystalline amino acids were added to meet minimum ratios and to ensure that lysine was first limiting. The second set of five diets were formulated to 1.3% TID lysine with increasing TID TSAA (0.56, 0.62, 0.68, 0.74, and 0.81%). The highest concentrations of both lysine and TSAA (1.3% and 0.81%, respectively) were combined as one treatment and used in both lysine and TSAA titrations to give a total of 10 treatments. The diets containing 0.9% TID lysine with 0.61% TID TSAA, 1.3% TID lysine with 0.56% TID TSAA, and 1.3% TID lysine with 0.81% TID TSAA were blended to form all other diets (Table 1).

All experimental diets were based on corn-soybean meal and were fed in a meal form throughout the 21-d experiment. Pigs were housed in the K-State Segregated Weaning Facility and allowed ad libitum access to feed and water through a dry feeder and one nipple waterer per pen. The pigs and feeders were weighed on d 7, 14, and 21 to determine ADG, ADFI, and F/G.

Blood samples were obtained by venipuncture on d 12 from two randomly selected pigs in each pen after a 3-h period of feed deprivation, and were analyzed for plasma urea N (PUN).

Data were analyzed as a randomized complete-block design with pen as the experimental unit. Pigs were blocked by weight at d 18 postweaning, and analysis of variance was performed by using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Linear and quadratic polynomial contrasts were performed to determine the effects of increasing dietary lysine and TSAA.

Results and Discussion

From d 0 to 21, increasing TID lysine increased (linear, $P<0.01$) ADG and decreased ADFI (linear, $P<0.06$). Increasing TID lysine improved (quadratic $P<0.02$) F/G, but the biggest improvement in feed efficiency occurred as TID lysine increased from 0.9 to 1.1%, with smaller improvements from 1.1 to 1.3%. In-

creasing TID TSAA increased (linear, P<0.03) ADG and improved (linear, P<0.01) F/G. Although there was a linear response to ADG and feed efficiency, only small improvements were observed as TID TSAA increased from 0.68 to 0.81%.

Blood analysis showed a decrease (linear, P < 0.01) in plasma urea N as both TID lysine and TSAA were increased in the experimental diets. This suggests that when dietary TSAA was insufficient, protein deposition was limited, resulting in increased urea in plasma. As dietary methionine increased, however, and approached the pig's requirement, N was redirected from urea to protein synthesis. In a typical amino acid dose-titration study, PUN and amino acid concentrations should decrease as the limiting amino acid is increased and approaches the pig's requirement.

Average daily gain and F/G were plotted on the Y axis, and TID lysine or TSAA were plotted on the X axis, to develop a trend line equation (Figures 1 and 2; Table 4). Similar points between TID lysine and TSAA for ADG and F/G were used to form a regression analysis and to determine an optimal lysine-to-TSAA ratio. Regression analysis of the response surface resulted in an estimated TID TSAA-to-lysine ratio range of 55 to 61% for ADG and 57 to 61% for F/G. The resulting TSAA-to-lysine ratio is slightly higher than the 57% value reported by the National Research Council.

The economic importance of determining the appropriate TSAA-to-lysine ratio is evident in that, as we increase or decrease the lysine content in the diet by increasing or decreasing soybean meal, the TSAA-to-lysine ratios also change. By establishing the optimal ratio, we can balance the diets accordingly. On the basis of this research, we suggest that the TSAA-to-lysine ratio for the pig up to 50 lb is from 57 to 61%.

Table 1. Composition of Diets (As-fed Basis)[ab]

	TID Lysine/TSAA, %		
Item, %	0.9/0.61	1.3/0.81	1.3/0.56
Corn	65.90	65.90	65.90
Soybean meal, 46.5% CP	27.65	27.65	27.65
Choice white grease	1.50	1.50	1.50
Monocalcium P (21% P, 18% C)	1.55	1.55	1.55
Limestone	0.95	0.95	0.95
Salt	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Antibiotic	0.50	0.50	0.50
L-isoleucine	---	0.02	0.02
L-valine	---	0.08	0.08
L-tryptophan	---	0.03	0.03
L-threonine	---	0.25	0.25
Alimet®	---	0.29	---
L-Lysine HCl	0.02	0.53	0.53
Corn starch	1.18	0.01	0.30
Total	100.00	100.00	100.00

[a]Diets that were formulated to contain 0.90/0.61 TID lysine/TSAA and 1.30/0.81 TID lysine/TSAA were blended to achieve TID lysine concentrations of 0.99, 1.07, 1.15, 1.22, and 1.30%.
[b]Diets that were formulated to be 1.30/0.56 TID lysine/TSAA and 1.30/0.81 TID lysine/TSAA were blended to achieve TID TSAA concentrations of 0.56, 0.62, 0.68, 0.74, and 0.81%.

Table 2. Effect of Increasing True-ileal-digestible (TID) Lysine in 20- to 50-lb Nursery Pigs[a]

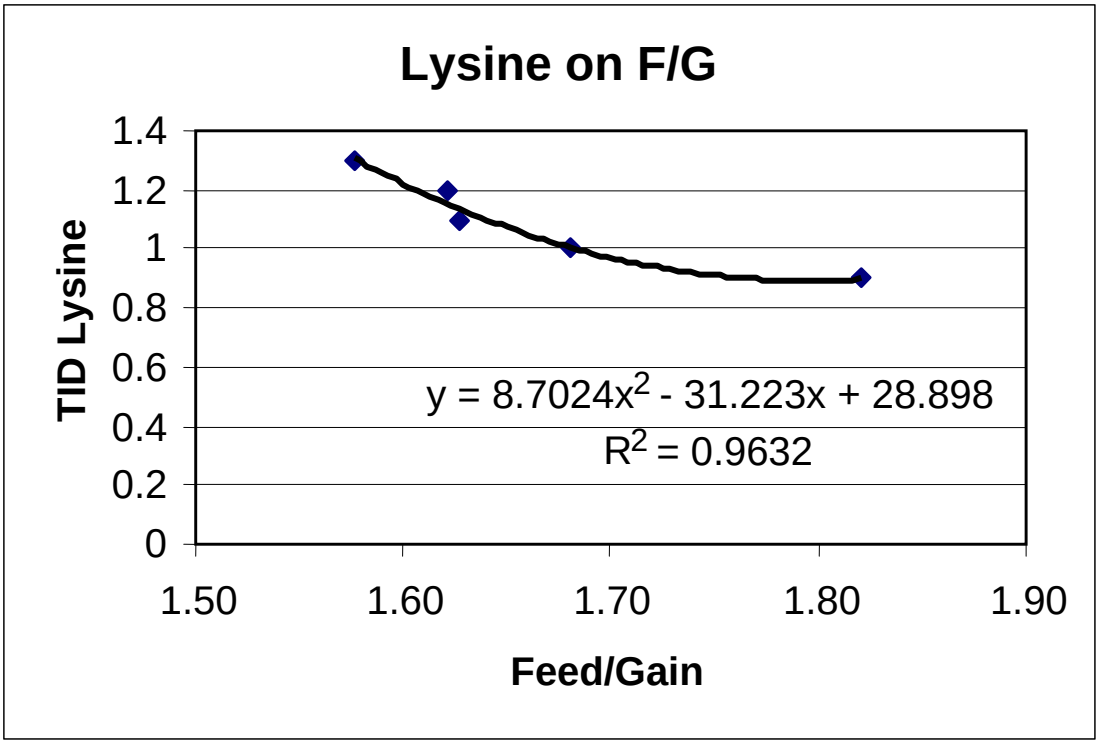
	TID lysine, %						P-value (P <)	
Item	0.9	1.0	1.1	1.2	1.3	SE	Linear	Quadratic
Day 0 to 21								
ADG, lb	1.09	1.15	1.18	1.15	1.21	0.04	0.01	0.51
ADFI, lb	1.99	1.94	1.92	1.86	1.91	0.08	0.06	0.34
F/G	1.83	1.68	1.63	1.62	1.57	0.03	0.01	0.02
Plasma urea N, mg/dL	4.32	2.79	3.04	2.23	1.88	0.35	0.01	0.29

[a]Each value is the mean of eight replications with 5 pigs (initially 22 lb) per pen.

Table 3. Effect of Increasing True-ileal-digestible (TID) Total Sulfur Amino Acids in 20- to 50-lb Nursery Pigs[a]

	TID TSAA, %						P-value (P <)	
Item	0.56	0.62	0.68	0.74	0.81	SE	Linear	Quadratic
Day 0 to 21								
ADG, lb	1.13	1.16	1.20	1.19	1.21	0.04	0.03	0.41
ADFI, lb	1.94	1.91	1.94	1.91	1.91	0.08	0.66	0.88
F/G	1.71	1.65	1.61	1.61	1.57	0.03	0.01	0.40
Plasma urea N, mg/dL	3.31	3.07	1.91	2.64	1.88	0.35	0.01	0.49

[a]Each value is the mean of eight replications with 5 pigs (initially 22 lb) per pen.



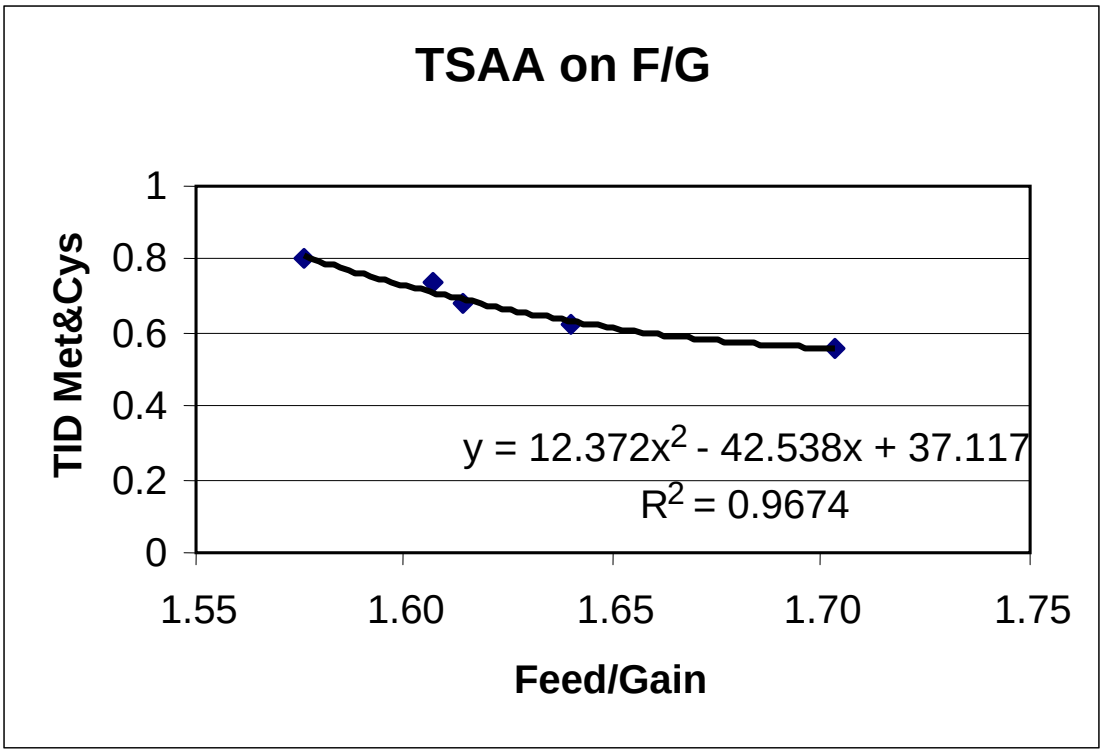
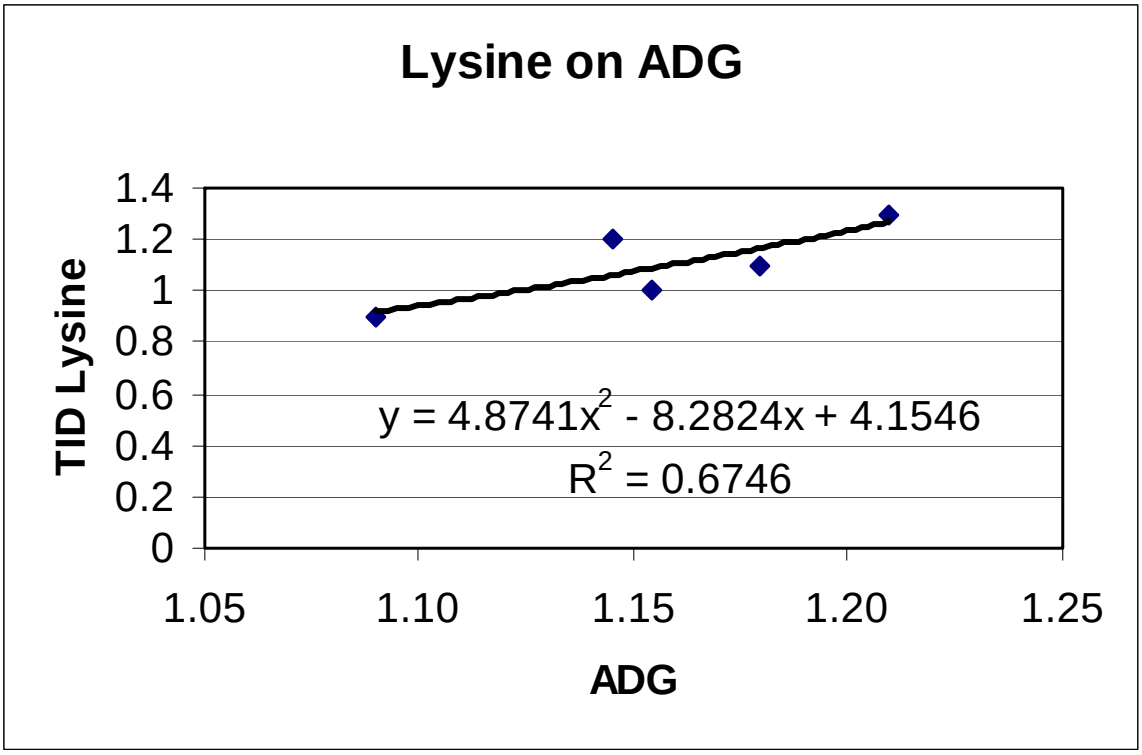


Figure 1. Regression Analysis for Lysine and TSAA for Feed Efficiency.



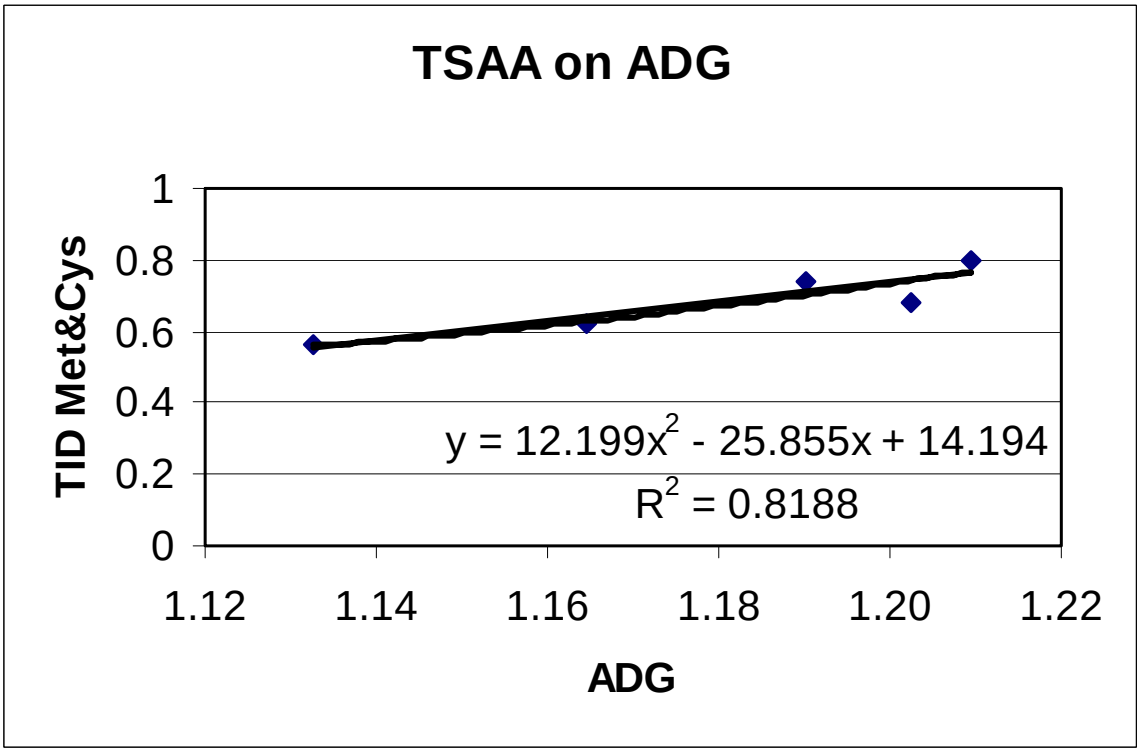


Figure 2. Regression Analysis for Lysine and TSAA on ADG.

Table 4. Regression Analysis of the Response Surface[a]

Response	TID Lysine	TID TSAA	TID TSAA-to-Lysine ratio
F/G			
1.69	0.98	0.55	56.7
1.67	1.03	0.58	56.2
1.64	1.10	0.63	56.9
1.59	1.26	0.76	60.3
ADG			
1.13	1.03	0.56	54.6
1.16	1.10	0.61	55.6
1.18	1.17	0.67	57.4
1.21	1.27	0.77	60.7

[a]Values for F/G and ADG were similar for pigs fed diets with increasing TID Lysine and TSAA.

Swine Day 2004

THE OPTIMAL TRUE-ILEAL-DIGESTIBLE LYSINE AND TOTAL SULFUR AMINO ACID REQUIREMENT FOR FINISHING PIGS FED PAYLEAN®[1]

N. Z. Frantz, M. D. Tokach, R. D. Goodband, J. L. Nelssen, S. S. Dritz[2], and J. M. DeRouchey

Summary

A total of 1887 pigs (PIC 337 × C22; 213 lb initial BW) were used in a 28-d growth assay to simultaneously examine both the true-ileal-digestible (TID) lysine and TID total sulfur amino acid (TSAA) requirements. The objective was to determine the appropriate TID TSAA-to-lysine ratio in finishing pigs fed Paylean® (4.5 g/ton) to maximize growth performance and carcass composition. Four TID lysine (0.66. 0.79, 0.92, and 1.05%) and four TID TSAA (0.47, 0.52, 0.57, and 0.63%) concentrations were evaluated. The highest lysine and TSAA concentrations were combined in the same diet, and there were eleven or twelve replicate pens per treatment. The lysine treatments were formulated with a minimum TID TSAA to lysine ratio of 60%, and the TSAA diets were formulated with 1.05% TID lysine. No gender × treatment or treatment × week interactions were observed (P>0.13). Increasing TID lysine increased ADG (linear, P<0.01), with the greatest response at 0.92% TID lysine, but ADG (P>0.76) was not affected by increasing TID TSAA. This resulted in a TID TSAA-to-lysine ratio of not more than 51% for optimum ADG. Increasing TID lysine did not affect ADFI (P>0.60), but ADFI decreased (linear, P<0.04) with increasing TID TSAA. Increasing dietary TID lysine improved feed efficiency (F/G) (linear, P<0.01), and increasing TID TSAA tended to improve F/G (linear, P<0.09). Although the response was linear, the greatest improvement in F/G was observed as the TID TSAA increased from 0.47% to 0.52%, resulting in an optimum TID TSAA-to-lysine ratio of 57%. Regression analysis indicates that the maximum F/G response was obtained with a TID TSAA-to-lysine ratio of 58%. Increasing TID lysine had no effect on any carcass criteria (P>0.11), but increasing TID TSAA from 0.47 to 0.52% tended to improve fat-free lean (quadratic, P<0.10). No other carcass criteria were affected by increasing TID TSAA (P>0.10). In summary, a TID TSAA-to-lysine ratio of 58% optimizes growth performance of finishing pigs fed Paylean.

(Key Words: Finishing Pigs, Lysine, Methionine, Paylean, Pigs, Sulfur Amino Acids.)

Introduction

Methionine is an essential amino acid used for protein synthesis. It is required for several metabolic pathways, and functions as a methyl donor. With other crystalline amino acids becoming more available and affordable, the exact ratios of essential amino acids to lysine must be understood to formulate diets having ideal amounts of amino acids. Using crystalline amino acids to replace intact protein sources will reduce N excretion and may increase dietary net energy.

[1]Appreciation is expressed to Novus Int. for partial financial support and for supplying the liquid methionine (Alimet®) and other amino acids used in our experiment.
[2]Food Animal Health and Management Center.

The current National Research Council estimates a TID TSAA concentration of 0.31% for barrows and 0.35% for gilts, with TID lysine concentrations of 0.52% and 0.59%, respectively, which results in a TID TSAA-to-lysine ratio of 59 to 60% for 176- to 265-lb pigs depositing 350 g/d of lean. The lysine requirement of pigs fed Paylean has been determined to be approximately 1.00% total dietary lysine, but there is no data available on the requirement for other amino acids in pigs fed Paylean. The objective of this experiment was to determine the response to dietary lysine and TSAA simultaneously to calculate a TID ratio that maximizes growth performance and carcass characteristics of finishing pigs fed Paylean.

Procedures

General

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. A total of 1,887 pigs (PIC line 337 × C22; 213 lb initial BW) were blocked by weight and sex in a 28-d growth assay. They were randomly allotted to one of seven dietary treatments. Four TID lysine (0.66, 0.79, 0.92, and 1.05%) and four TID TSAA (0.47, 0.52, 0.57, and 0.63%) concentrations were evaluated. The highest lysine and TSAA concentrations were combined in the same diet (Table 1). Either L-lysine HCl or methionine hydroxy analogue (Alimet®), along with L-threonine, replaced corn and was used to obtain the increasing dietary concentrations of lysine or TSAA. Alimet was supplemented to provide an equivalent bioactivity on an equal molar basis, or 88% of the bioactivity of DL-methionine on a weight basis. All diets contained 4.5 g/ton Paylean. The values used in diet formulation and TID digestibilities were based on those published by the National Research Council. Diet samples were analyzed for amino acid content (Novus Int., St. Louis, MO). Experimental diets were fed in meal form for 28 d.

Table 1. Diet Composition (As-fed Basis)[abc]

Item	
Ingredient, %	
Corn	75.70
Soybean meal (46.5% CP)	18.50
Choice white grease	2.50
Monocalcium phosphate (21% P)	0.80
Limestone	0.88
Salt	0.35
Vitamin premix with phytase	0.06
Trace mineral premix	0.06
L-Lysine HCl	0.50
Methionine[d]	0.18
L-Threonine	0.28
L-Valine	0.09
L-Isoleucine	0.09
L-Tryptophan	0.04
Paylean®	0.03
Calculated Analysis	
Total lysine, %	1.15
True-ileal-digestible amino acids	
Lysine, %	1.05
Isoleucine:lysine ratio, %	0.60
Leucine:lysine ratio, %	1.23
Methionine:lysine ratio, %	0.36
Met & Cys:lysine ratio, %	0.60
Threonine:lysine ratio, %	0.72
Tryptophan:lysine ratio, %	0.18
Valine:lysine ratio, %	0.68
ME, kcal/lb	1,566
CP, %	15.1
Ca, %	0.57
P, %	0.51
Lysine:calorie ratio, g/mcal	3.33

[a]Diets fed in meal form for 28 d. [b]Methionine was replaced with corn, resulting in four TID TSAA treatments (0.47, 0.52, 0.57, and 0.63%), whereas crystalline lysine and other amino acids were replaced by corn, resulting in four TID lysine treatments (0.66, 0.79, 0.92, and 1.05%). [c]Analyzed values for diets with 0.66, 0.79, 0.92, and 1.05% TID lysine were 0.68, 0.81, 0.98, and 1.14% total lysine, respectively, and the diets containing 0.47, 0.52, 0.57, and 0.63% TID TSAA were 0.52, 0.58, 0.63, and 0.73% TSAA, respectively. [d]Methionine supplied as liquid methionine hydroxy analogue (Alimet®).

Growth Performance and Carcass Composition

Pigs and feeders were weighed on d 0, 14, and 28 to determine ADG, ADFI, and F/G. At the end of the trial period, pigs were weighed before transport to a USDA-inspected processing plant (Swift and Co., Worthington, MN), where carcass data were collected. Before transport, the pigs in each pen were marked with a distinctive tattoo to allow the carcass data to be recorded for each pen. Carcass data were collected by pen to evaluate 10th-rib backfat depth, longissimus depth, lean percentage, fat-free-lean index, yield, and hot-carcass weight. Yield was calculated as hot-carcass weight divided by live weight. Fat depth and longissimus depth were measured with an optical probe inserted at the 10th rib, 7 cm off of the midline of the hot carcass. Lean percentage was provided from the packing plant, according to a proprietary equation, and fat-free-lean index was calculated.

Housing

The experiment was conducted at a commercial research facility in southwestern Minnesota. The facility is made up of four individual barns, each 41 × 250 ft, with 48 totally slatted concrete pens (10 × 18 ft). Each pen was equipped with a four-hole dry self-feeder (Staco, Schaefferstown, PA) and one-cup waterer to allow ad libitum access to feed and water. The finishing facilities were double curtain-sided, deep-pit barns that operate on manual ventilation during the summer and on automatic ventilation during the winter. The study was conducted in two barns; 42 pens from one, and 40 pens from the second were used.

Animals

Each pen contained 24 ± 2 pigs per pen, with number of pigs per pen balanced across treatment and eleven or twelve replicates (pens) per treatment. Two barns were used, one with six complete replications (three barrow and three gilt), and the other with five complete replications (three barrow and two gilt) and one incomplete block that had the 0.79- and 0.92%-TID-lysine treatments deleted because of a limited number of pigs in the barn.

Statistical Analysis

Data were analyzed as a randomized incomplete-block design by using the PROC MIXED procedure of SAS, with pen as the experimental unit. The statistical model included the effects of dietary treatment, gender, and their interaction analyzed as fixed effects, and the effect of weight block was included as a random effect. Also, linear and quadratic polynomial contrasts were performed to determine the effects of increasing dietary lysine and TSAA.

Results and Discussion

No treatment × gender or treatment × week interactions were observed (P>0.13) on growth performance or carcass data. There were differences (P<0.01) between barrows and gilts for ADG (2.34 vs. 2.07 lb), ADFI (6.77 vs. 5.86 lb), backfat (0.76 vs. 0.62 in), % lean (54.03% vs. 56.60%), and fat-free lean (49.43 vs. 51.10%).

From d 0 to 14, increasing TID lysine improved ADG (linear, P<0.01) and F/G (linear, P<0.01), but did not affect ADFI (P>0.40; Table 2). From d 14 to 28, increasing TID lysine had no effect on any response criteria (P>0.11). For the overall study, increasing TID lysine improved ADG (linear, P<0.01) and F/G (linear, P<0.01), but did not affect ADFI (P>0.60).

From d 0 to 14, increasing TID TSAA had no effect on any performance criteria (P>0.28; Table 3). From d 14 to 28, increasing TID TSAA did not affect ADG (P>0.37), but improved F/G (linear, P<0.02) and decreased ADFI (linear, P<0.03). The greatest response to TID TSAA occurred from d 14 to 28. For the overall study, increasing dietary TID TSAA did not affect ADG (P>0.76). Accord-

ing to this result, pigs fed Paylean require no more than 0.47% TSAA and a TID TSAA-to-lysine ratio not greater than 51% for optimum ADG when 0.92% TID lysine is the requirement. Increasing TID TSAA decreased ADFI (linear, P<0.04) and tended to improve F/G (linear, P<0.09). Although linear, the greatest improvement in F/G was observed as dietary TSAA concentration was increased from 0.47 to 0.52% and as TID lysine was increased to 0.92%. Thus, when a value of 0.52% TSAA is used, a ratio of 57% is optimum for F/G.

Increasing dietary TID lysine had no effect on carcass measurements (P>0.11; Table 4).

Increasing TID TSAA tended to improve fat-free lean (quadratic, P<0.10), with the maximum value occurring at 0.52% TID TSAA. Feeding more than 0.52% TID TSAA did not further improve carcass traits. No other carcass measurements (P>0.13; Table 5) were affected by increasing TID TSAA.

The TID TSAA-to-lysine ratio for finishing pigs fed 4.5 g/ton Paylean in this study is not greater than 51% for ADG and 57% for F/G. To further verify our TSAA-to-lysine ratio, the range of F/G values obtained in the study were used in regression analysis to predict the lysine and TSAA requirements. Thus a ratio for different levels of pig performance was established. Because there was no ADG response to additional TSAA, these values could not be used in the regression analysis to determine a TSAA-to-lysine ratio for optimum ADG. True-ileal-digestible lysine and TSAA concentrations were plotted for the range of F/G values observed from the study, and a trendline was calculated (Figures 1 and 2). On the basis of regression equations, the TSAA-to-lysine ratio necessary to achieve a given level of pig performance was determined (Table 6). These results indicate that F/G is maximized at a TSAA-to-lysine ratio of 58%.

Further research is needed to verify the ideal amino acid pattern for pigs fed Paylean; from our study, however, the TID lysine requirement is 0.92%, and the TID TSAA-to-lysine ratio is not greater than 58%.

Table 2. Effect of Increasing True-ileal-digestible (TID) Lysine in Finishing Pigs Fed Paylean[ab]

	TID Lysine %					P-value	
Item	0.66	0.79	0.92	1.05	SE	Linear	Quadratic
Day 0 to 14							
ADG, lb	2.16	2.29	2.43	2.40	0.104	0.01	0.29
ADFI, lb	6.24	6.35	6.39	6.37	0.155	0.62	0.55
F/G	2.89	2.77	2.63	2.65	0.118	0.01	0.39
Day 14 to 28							
ADG, lb	1.98	1.98	2.00	2.09	0.104	0.26	0.45
ADFI, lb	6.24	6.20	6.17	6.24	0.155	0.90	0.59
F/G	3.15	3.13	3.09	2.99	0.118	0.11	0.60
Day 0 to 28							
ADG, lb	2.07	2.14	2.23	2.25	0.074	0.01	0.75
ADFI, lb	6.24	6.28	6.28	6.31	0.109	0.60	0.93
F/G	3.01	2.93	2.82	2.80	0.084	0.01	0.66

[a]Values for each treatment are the mean of 11 or 12 replications with 24 ± 2 pigs per pen (PIC 337 × C22, initially 213 lb). [b]Note that the values for pigs fed the 1.05% TID lysine are the same as those fed the 0.63% TSAA diet (Table 2) because they were the same dietary treatment.

Table 3. Effect of Increasing the True-ileal-digestible (TID) Total Sulfur-containing Amino Acids (TSAA) in Finishing Pigs Fed Paylean[a]

	TID TSAA, %					P-value	
Item	0.47	0.52	0.57	0.63	SE	Linear	Quadratic
Day 0 to 14							
ADG, lb	2.47	2.45	2.36	2.40	0.099	0.40	0.66
ADFI, lb	6.44	6.35	6.22	6.37	0.148	0.46	0.28
F/G	2.61	2.59	2.64	2.65	0.113	0.63	0.96
Day 14 to 28							
ADG, lb	2.03	2.03	2.12	2.09	0.099	0.37	0.91
ADFI, lb	6.61	6.28	6.37	6.24	0.148	0.03	0.32
F/G	3.26	3.09	3.00	2.99	0.113	0.02	0.49
Day 0 to 28							
ADG, lb	2.26	2.24	2.24	2.26	0.070	0.99	0.76
ADFI, lb	6.52	6.31	6.29	6.30	0.105	0.04	0.14
F/G	2.89	2.82	2.81	2.80	0.080	0.09	0.46

[a]Values for each treatment are the mean of 12 replications with 24 ± 2 pigs per pen (PIC 337 × C22, initially 213 lb).

Table 4. Effect of Increasing True-ileal-digestible (TID) Lysine on Carcass Characteristics of Finishing Pigs Fed Paylean[a]

	TID Lysine %					P-value	
Item	0.66	0.79	0.92	1.05	SE	Linear	Quadratic
10th-rib backfat depth, in	0.70	0.69	0.69	0.68	0.014	0.70	0.53
Loin eye depth, in	2.31	2.32	2.34	2.37	0.035	0.54	0.11
Lean, %[b]	55.14	55.27	55.33	55.54	0.288	0.58	0.24
Fat-free-lean index, %[c]	50.04	50.21	50.17	50.29	0.196	0.74	0.44
Yield, %	75.58	75.80	76.03	76.00	0.399	0.79	0.23
Hot-carcass wt, lb	200.55	202.05	202.10	202.62	0.888	0.99	0.43

[a]Values are the mean of 11 or 12 replications with 24 ± 2 pigs per pen (PIC 337 × C22, initially 213 lb).
[b]Lean percentage was supplied from the packing plant, using a proprietary equation.
[c]Fat-free-lean index was calculated according to National Pork Producers Council (NPPC) 1994 procedures.

Table 5. Effect of Increasing True-ileal-digestible (TID) Total Sulfur-containing Amino Acids (TSAA) on Carcass Characteristics of Finishing Pigs Fed Paylean[a]

	TID TSAA, %					P-value	
Item	0.52	0.58	0.63	0.68	SE	Linear	Quadratic
10th-rib backfat depth, in	0.69	0.67	0.68	0.68	0.014	0.71	0.13
Loin eye depth, in	2.33	2.39	2.37	2.37	0.035	0.36	0.19
Lean, %[b]	55.34	55.83	55.63	55.54	0.288	0.65	0.14
Fat-free-lean index, %[c]	50.18	50.51	50.41	50.29	0.196	0.74	0.10
Yield, %	75.88	75.80	75.96	76.00	0.399	0.68	0.83
Hot-carcass wt, lb	202.60	204.17	204.44	202.63	1.957	0.96	0.21

[a]Values are the mean of 12 replications with 24 ± 2 pigs per pen (PIC 337 × C22, initially 213 lb).
[b]Lean percentage was supplied from the packing plant using a proprietary equation.
[c]Fat-free-lean index was calculated according to National Pork Producers Council (NPPC) 1994 procedures.

Table 6. Estimation of True-ileal-digestible (TID) Lysine and TSAA Requirement, and thus a TSAA-to-Lysine Ratio, Based on Regression Analysis for Different Levels of Pig Performance[a]

Item	Lysine	TSAA	TSAA:lysine	% of max	% of min
Feed Efficiency[b]					
2.80	1.02	0.59	58	100	103.6
2.85	0.93	0.52	57	98.3	101.8
2.90	0.84	0.46	55	96.6	100

[a]The feed efficiencies were plotted against TID lysine and TSAA concentrations used in the experiment to determine a TID lysine and TSAA concentration necessary to achieve a given feed efficiency and thus, a TID TSAA-to-lysine ratio.
[b]Regression equations of $y = 1.45x^2 – 10.027x + 17.729$ and $y = -1.2869x + 4.1925$ were used to determine lysine and TSAA requirements, respectively, for the range of feed-efficiency values.

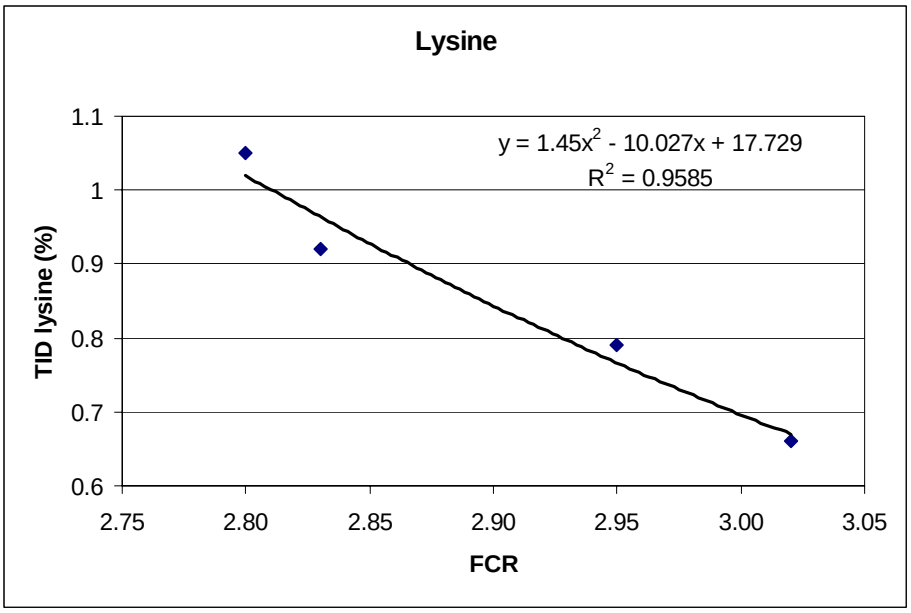


Figure 1. The Effect of TID Lysine on Feed Efficiency (FCR) of Pigs Fed Paylean. A total of 1887 pigs (initially 213 lb) with 24 ± 2 pigs per pen and 11 or 12 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible lysine concentrations were 0.66, 0.79, 0.92, and 1.05%. The range of feed-efficiency values were plotted against TID lysine concentrations used in the experiment to determine the lysine concentration necessary to achieve a certain feed efficiency.

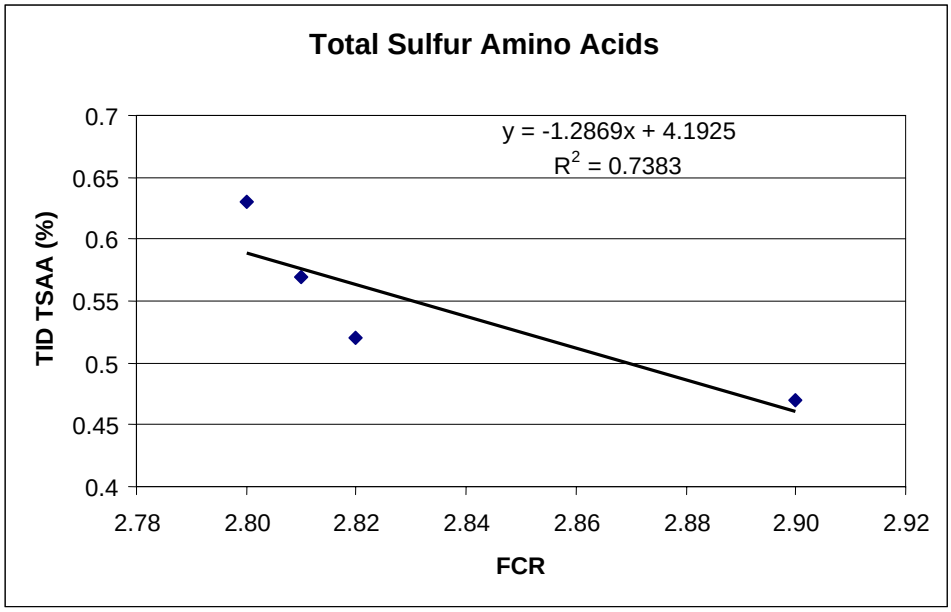


Figure 2. Effects of Increasing TID TSAA on Feed Efficiency (FCR) of Pigs Fed Paylean. A total of 1887 pigs (initially 213 lb) with 24 ± 2 pigs per pen and 11 or 12 pens per treatment. Experimental diets were fed for 28 d. True-ileal-digestible TSAA concentrations were 0.52, 0.58, 0.63, and 0.68%. The range of feed-efficiency values were plotted against TID TSAA concentrations used in the experiment to determine the TSAA-to-lysine ratio necessary to achieve a certain feed efficiency.

EFFECTS ON OVERALL PERFORMANCE OF FEEDING COMMERCIALLY GROWN PIGS LESS OR MORE THAN THEIR LYSINE REQUIREMENT IN EARLY AND LATE FINISHING[1]

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Summary

A total of 1154 gilts (PIC L337 × C22, initially 72.3 ± 1.7 lb) were used to determine effects on subsequent growth performance of feeding less than or at the estimated lysine requirement for optimal growth and feed efficiency in early finishing (70 to170 lb). From d 0 to 27 and d 27 to 55, pigs were fed a diet containing 2.75 and 2.25 g lysine/Mcal ME, respectively, which was less than their estimated requirement. Pigs fed at their estimated requirements were provided diets containing 3.30 and 2.75 g lysine/Mcal ME from d 0 to 27 and 27 to 55, respectively. Pigs within each early finishing treatment subsequently were fed less than, at, or more than (1.75, 2.25, 2.75 g lysine/Mcal ME, respectively) the estimated lysine requirement from 170 lb to slaughter at 255 lb. In early finishing (70 to 170 lb), pigs fed at the estimated lysine requirement had improved (P<0.003) ADG, feed efficiency, and income over marginal feed costs (IOMFC) compared with those of pigs fed less than their estimated dietary lysine requirement. But pigs fed less than the lysine requirement had lower (P<0.001) feed cost per pound of gain. In late finishing (170 to 255 lb), ADG, feed efficiency, feed cost per pound of gain, and IOMFC improved (quadratic, P<0.006) with increasing dietary lysine, and were optimized at the estimated lysine requirement (2.25 g lysine/Mcal ME). Pigs fed lysine-deficient diets in early finishing had improved (P<0.005) feed efficiency and feed cost per pound of gain in late finishing, compared with those of pigs fed adequate lysine in early finishing. Carcass lean measures improved (quadratic, P<0.02) with increasing dietary lysine in late finishing. Feed costs per pound of gain from d 0 to 104 were increased (P<0.001) when feeding increased dietary lysine in early finishing, and were not affected (P>0.17) by late-finishing dietary treatment. Overall IOMFC was not affected (P>0.62) by the lysine-to-calorie ratio (g lysine/Mcal ME) fed in early finishing (70 to 170 lb), and increased (linear, P<0.02) with increasing lysine in late finishing (170 to 255 lb). But increasing dietary lysine from 2.25 to 2.75 g lysine/Mcal ME in late finishing did not improve (P>0.89) d 0 to 104 IOMFC. Due to compensatory improvements in late finishing feed efficiency and feed cost per pound of gain, pigs fed diets less than biological requirements in early finishing, and subsequently fed at the estimated lysine requirement in late finishing, had lower (0.145 vs. 0.148 ± $0.001, P<0.03) feed cost per pound of gain, and similar IOMFC (79.62 vs. 79.13 ± $ 0.62 per head, P>0.70) to that of pigs fed at the estimated dietary lysine requirement throughout finishing. Understanding the biologic and economic dynamics of over- and

[1]Appreciation is expressed to New Horizon Farms, Pipeston, MN, and its employees for use of pigs, facilities, and technical assistance.

[2]Food Animal Health and Management Center.

under-feeding lysine in early (70 to 170 lb) and late (170 lb to 255 lb) finishing provides guidance in formulating cost-effective feeding strategies. This study suggests that, as long as lysine requirements are being met in mid-late finishing (170 lb to slaughter), feeding slightly less than the lysine requirement for optimal performance in early finishing reduces feed costs without sacrificing overall IOMFC.

(Key Words: Compensatory Gain, Lysine, Pigs.)

Introduction

Understanding the effects of lysine:calorie ratio (g lysine/Mcal ME) on growth rate, feed efficiency, carcass composition, and economic return is essential in the development of cost-effective feeding programs for growing pigs. Recent research indicates pigs fed high-energy diets (1,624 kcal ME/lb) in early finishing (<150 lb) have only modest improvements in growth and feed efficiency over a broad range of lysine:calorie ratios (g lysine/Mcal ME). In these studies, feed cost per pound of gain increased linearly with increasing lysine:calorie ratio. But IOMFC was maximized as the biological requirements for optimizing growth and feed efficiency were met. On the other hand, pigs in late finishing (>150 lb) had larger improvements in gain, feed efficiency, feed cost per pound of gain, and IOMFC as the lysine-to-calorie ratio increased. These studies indicated that feed cost per pound of gain was improved, and reductions in IOMFC were rather modest, when feeding marginal, lysine-deficient diets early in the grow-finish period, compared with the rather severe economic penalties of feeding marginally deficient diets in late finishing (> 150 lb). Therefore, the objective of this study was to determine the biologic and economic effects of feeding finishing pigs less than or at estimated dietary lysine requirements in early (< 170 lb) finishing, and subsequently feeding them less than, at, or more than lysine requirements from 170 lb to slaughter.

Procedures

Forty-two pens of pigs, with 27 to 28 gilts per pen (n =1,154, PIC L337 × C22, initially 72.3 ± 1.7 lb), were used to determine the effects of feeding less than (phase 1, d 0 to 27 = 2.75; phase 2, d 27 to 55 = 2.25 g lysine/Mcal ME) or at (phase 1, d 0 to 27 = 3.30; phase 2 d 27 to 55 = 2.75 g lysine/Mcal ME) the estimated lysine requirement for optimal growth and feed efficiency. Seven pens of pigs within each early finishing treatment (or whole plot) were then fed less than, at, or more than (1.75, 2.25, 2.75 g lysine/Mcal ME, respectively) the estimated lysine requirement in phase 3 (d 55 to 104) of this study. An overview of trial design, feeding phases, lysine requirement classifications, and diet information are outlined in Tables 1 and 2. The estimated lysine requirements used were determined in previous series of studies in these commercial finishing research facilities with same genotype and pig source (i.e., estimated lysine requirements for gilts from 70 to 265 lb, g lysine/Mcal ME = -0.00744 × BW, lb + 4.004).

All diets were based on corn-soybean meal, with 6% added choice white grease. Lysine:calorie ratios (g lysine/Mcal ME) were achieved by manipulating the ratio of corn to soybean meal. To ensure that lysine was the first-limiting amino acid, no crystalline lysine was used. All other nutrients were formulated to be non-limiting. The lysine:calorie ratios discussed in this paper are expressed as total grams lysine:Mcal of ME according to National Research Council's values for ingredient nutrient content. Lysine expressed as a percentage of the diet is illustrated in Table 2. A subsample of each diet was analyzed for lysine content, and all values were within analytical variation of calculated values.

Each pen was 10 ft × 18 ft, with a 4-hole self-feeder and one cup waterer. Finishing facilities were total slatted, deep pitted, and

double curtain-sided, with a total of 48 pens per barn. Pig weights by pen and feed disappearance were measured throughout the 104-d trial period. Four pigs per pen were sold to slaughter on d 83. The remaining pigs in each pen were weighed and tattooed with a unique tattoo number on d 104. Pen identification was maintained through the packing plant to enable carcass data (carcass yield, fat and loin depth at the 10th rib, lean percentage, and grade premium) to be collected for each pen. Gain, feed intake, feed conversion, feed cost per pound of gain, and IOMFC were measured. Income over marginal feed costs is defined as the value of the pigs weighed off-test, less the feed costs incurred during the trial period. In each phase (phases 1, 2, and 3), an average pig value was calculated by assessing value to the weight gained during that feeding phase at $40.00/CWT. Feed costs incurred during each phase were then subtracted from the derived value of the weight gain to calculate IOMFC for each pen. In evaluating the overall trial (d 0 to 104), an average pig value was calculated by using the calculated carcass weight and carcass grade-premium data from each pen. Calculated carcass weight was derived by multiplying average sale weight by the carcass yield for each pen. Average feed cost per pig was then subtracted from the derived pig value to attain the IOMFC for each pen.

Data from early finishing (phases 1 and 2) were analyzed to determine differences in being fed less than or at the estimated lysine requirement (i.e., whole plot treatments) from 70 to 170 lb. Data from late finishing and the overall d 0 to104 trial data were analyzed as a split plot, with whole-plot effects of early finishing dietary treatment (less than or at estimated lysine requirement), and subplot effects of increasing lysine-to-calorie ratio (g lysine/ Mcal ME) in late finishing. Pen was used as the experimental unit for all data in the analyses.

Results and Discussion

In phases 1 (70 to 120 lb) and 2 (120 to 170 lb), ADG, feed efficiency, and IOMFC improved ($P<0.01$, Tables 3 and 4) as lysine:calorie ratio increased from 2.75 to 3.30 and from 2.25 to 2.75, respectively. But feed cost per pound of gain was reduced ($P<0.0005$) in pigs fed 2.75 g lysine/Mcal ME in phase 1. Feed cost per pound of gain was not affected ($P>0.27$) by dietary treatment in phase 2. When collectively evaluating early finishing (phases 1 and 2, 70 to 170 lb) performance, ADG, feed efficiency, and IOMFC improved ($P<0.003$, Table 4) in pigs fed 3.30 and 2.75 g lysine/Mcal ME in phases 1 and 2 respectively. But feed cost per pound of gain was reduced ($P<0.001$) in pigs fed 2.75 and 2.25 g lysine/Mcal ME in phases 1 and 2. These results agree with previous research indicating feed cost per pound of gain is reduced when feeding less than the lysine biological requirement for optimal growth and efficiency in early (<170 lb) finishing. But IOMFC improves when increasing dietary lysine improves growth and feed efficiency.

In late finishing (phase 3, 170 to 255 lb), pigs in 7 pens within each early-finishing treatment (less than or at estimated lysine requirement) were fed 1.75, 2.25, or 2.75 g lysine/Mcal ME diets. In the first 28 days of late finishing (170 to 220 lb), ADG, ADFI, feed efficiency, feed cost per pound of gain, and IOMFC improved (linear, $P<0.05$, Table 5) as dietary lysine increased. Pigs fed lysine-limiting diets in early finishing (70 to 170 lb) had improved ADG ($0.13 \pm .06$ lb/d, $P = 0.05$) compared with that of pigs fed adequate lysine diets in early finishing when fed 2.25 or 2.75 g lysine:Mcal ME in late finishing. Feed efficiency (2.67 vs. 2.75 ± 0.02) and feed cost per pound of gain (0.158 vs. $0.163 \pm \$ 0.001$) improved ($P<0.002$) in pigs fed lysine-limiting diets in phases 1 and 2, with those of compared to pigs fed adequate lysine in early finishing. These compensatory improvements in

feed efficiency suggest that lean deposition may increase in pigs previously being fed diets deficient in dietary lysine.

In the final 11 days of late finishing (220 to 255 lb), ADG, feed efficiency, feed cost per pound of gain, and IOMFC improved (quadratic, P<0.01) with increasing dietary lysine. These parameters were optimized at 2.25 g lysine/Mcal ME. Early-finishing dietary treatment did not affect (P>0.16) parameters measured the final 11 days before slaughter.

In evaluating the entire late-finishing feeding period (170 to 255 lb), ADG and feed efficiency improved (quadratic, P<0.006) with increasing dietary lysine. Gain and feed-efficiency improvements were minimal beyond 2.25 g lysine/Mcal ME. Pigs fed lysine-limiting diets in early finishing had improved feed efficiency (2.73 vs. 2.80 ± .01, P<0.005) and feed cost per pound of gain (0.161 vs. 0.166 ± $0.0008, P < 0.005) in late finishing, compared with that of pigs fed adequate lysine in early finishing. Feed cost per pound of gain and IOMFC improved (quadratic, P<0.002) with increasing lysine in late finishing. Feed cost per pound of gain and IOMFC were optimized at 2.25 g lysine/Mcal ME.

In evaluating the entire 104-d feeding period, ADG and feed efficiency improved due to increasing lysine in early (P<0.02, Table 6) and late finishing (linear, P<0.001, quadratic P < 0.10). Minimal improvements in gain and feed efficiency occurred due to increasing lysine to more than 2.25 g lysine/Mcal ME in late finishing. Feed cost per pound of gain increased (0.146 vs. 0.149 ± $0.0005, P<0.001) in pigs fed increased lysine in early finishing, but was not affected (P>0.17) by phase 3 dietary lysine. Carcass yield was not affected (P>0.20) by dietary treatment, but 10th rib backfat, loin depth, lean percentage, and lean premium improved (quadratic, P<0.02) as late-finishing dietary lysine increased. Although carcass lean measures were optimized when 2.25 g lysine/Mcal ME was fed at late finishing, numeric improvements in backfat and lean percentage were observed as lysine increased to 2.75 g lysine/Mcal ME. Pigs fed the lysine-deficient diets in early finishing tended to have increased 10^{th}-rib backfat (0.67 vs. 0.65 ± .009, P<0.09). But reducing dietary lysine in early finishing did not affect loin depth (2.24 vs. 2.24 ± 0.01 in, P>0.89) or lean percentage (55.3 vs. 55.6 ± 0.15%, P>0.13). Carcass weight, carcass value, and feed costs per pig increased due to increasing dietary lysine in both early (P<0.04) and late (linear, P<0.02) finishing. Income over feed cost was not affected (P>0.62) by dietary lysine treatment fed in early finishing, but IOMFC improved (linear, P<0.01, quadratic, P<0.11) with increasing lysine in late finishing. Although the effects of phase 3 dietary lysine on IOMFC were linear, numeric improvements were not observed in treatments in excess of 2.25 g lysine/Mcal ME.

Pigs fed less than the dietary lysine requirements for optimal growth and efficiency in early finishing did not compensate for gain differences during early finishing. [i.e., d 55 weights = 168.7 vs.173.9 ± 1.09 lb (SED). with sale weights = 252.8 vs. 256.0 ± 0.67 lb (SED) for pigs fed the limiting and adequate lysine diets in early finishing, respectively]. But pigs fed diets having less than the biological requirement in early finishing had compensatory improvements (P<0.005) in feed efficiency and feed cost per pound of gain in late finishing. Therefore, pigs fed diets having less than the biological requirement in early finishing, and subsequently fed at (2.25 g lysine/Mcal ME) the biological requirement in late finishing, had lower (P<0.03) feed cost per pound of gain and similar IOMFC (83.46 vs. 82.97 ± $ 1.33 per head, P>0.72), compared with those of pigs fed adequate dietary lysine throughout finishing.

Understanding the biologic and economic effects of lysine-to-calorie ratio in both early (70 to 170 lb) and late (170 to 255 lb) finish-

ing provides guidance in formulating cost-effective feeding strategies. These data support previous research indicating that penalties for feeding high-energy diets having less than the lysine-to-calorie ratio required for optimum growth and efficiency in early finishing (<150 to 170 lb) are modest, and feed cost per pound of gain is reduced. But the biologic and economic penalties for feeding less than the estimated dietary lysine requirement in late finishing (>150 to 170 lb) are rather severe.

Table 1. Overview of Trial Design[a]

Phases 1 and 2					
Estimated Lysine Requirement Status					
Deficient			Optimum		
21 pens			21 pens		
Phase 3[b]					
Estimated Lysine Requirement Status					
Deficient	Optimum	Excess	Deficient	Optimum	Excess
7 pens	7 pens	7 pens	7 pens	7 pens	7 pens

[a]Studies were conducted to evaluate effects of feeding grow-finish gilts (PIC L337 x C22, n= 1154) either less than (deficient) or at (optimum) the estimated lysine requirement for optimal performance in early (70 to 170 lb) finishing, and subsequently feeding less than, at, or more than (excess) the estimated lysine requirement in late (170 to 255 lb) finishing.
[b]Pigs in seven pens within phase 1 and phase 2 dietary treatment (21 pens) were subsequently fed one of three diets of increasing dietary lysine in phase 3.

Table 2. Description of Feeding Phases, Lysine Requirement Status, and Trial Diets[a]

	Duration, Day	Weight Range, lb	Estimate Lysine Requirement Status	Lysine:Calorie Ratio (g lysine: Mcal ME)	Total Lysine, %	TID Lysine, %	Cost/Ton $
			Deficient	2.75	0.99	0.81	123.65
Phase 1	0 to 27	70 to 120	Optimum	3.30	1.18	0.99	129.51
			Deficient	2.25	0.81	0.7	118.28
Phase 2	0 to 27	120 to 170	Optimum	2.75	0.99	0.81	123.69
			Deficient	1.75	0.63	0.54	112.97
			Optimum	2.25	0.81	0.70	118.28
Phase 3	55 to 104	170 to 255	Excess	2.75	0.99	0.81	123.69

[a]Dietary treatments were divided into three phases of growth, with pigs being fed either less than (deficient) or at (optimum) the estimated lysine requirement for optimal biological performance in phase 1 and phase 2, and subsequently fed either less than, at, or more than (excess) the estimated lysine requirement in phase 3.

[b]Diet costs were calculated with $ 1.85/bu corn and $150/ton, 46.5% soybean meal, along with a $12/ton manufacturing and delivery charge.

Table 3. Effects of Feeding Less Than or at the Estimated Lysine Requirement in 70- to 120-lb Gilts[a]

	Lysine:Calorie Ratio, (g lysine/Mcal ME)			
	2.75	3.3		
	Total Lysine, %			
	0.99	1.18		
	Estimated Requirement Status			
Item, day 0 to 27	Deficient	Optimum	SEM	Probability (P<)
Weight day 0, lb	72.2	72.4	1.68	0.64
ADG, lb	1.68	1.75	0.02	0.008
ADFI, lb	3.53	3.47	0.04	0.15
F/G	2.10	1.99	0.01	0.0001
Feed cost / lb, $	0.124	0.129	0.0009	0.0005
IOMFC, $/hd[b]	11.61	11.85	0.19	0.24
Weight d 27, lb	117.76	120.27	2.21	0.003

[a]A total of 1154 gilts (PIC L337 * C22) housed at the rate of 27 to 28 pigs/pen and 21 replications per treatment in phase 1 (d 0 to 27) were used to evaluate effects of feeding less than (deficient) or at (optimum) the estimated lysine:calorie ratio (g lysine:Mcal ME) for optimal growth and efficiency.
[b]Income over marginal feed costs = Value of gain on a $40/CWT live weight basis - feed costs during trial period.

Table 4. Effects of Feeding Less Than or at the Estimated Lysine Requirement in 120- to 170-lb Gilts[a]

	Lysine:Calorie Ratio, (g lysine/Mcal ME)			
	2.25	2.75		
	Total Lysine, %			
	0.81	0.99		
	Estimated Requirement Status			
Item, day 27 to 55	Deficient	Optimum	SEM	Probability (P<)
ADG, lb	1.80	1.90	0.02	0.0001
ADFI, lb	4.26	4.34	0.04	0.07
F/G	2.37	2.28	0.02	0.0001
Feed cost / lb, $	0.140	0.141	0.001	0.27
IOMFC, $/hd[b]	12.12	12.70	0.15	0.002
Weight d 55, lb	168.7	173.9	2.40	0.0001

[a]A total of 1154 gilts (PIC L337 * C22) housed at the rate of 27 to 28 pigs/pen and 21 replications per treatment in phase 2 (d 27 to 55) were used to evaluate effects of feeding less than (deficient) or at (optimum) the estimated lysine:calorie ratio (g lysine:Mcal ME) for optimal growth and efficiency.
[b]Income over marginal feed costs = Value of gain on a $40/CWT live weight basis – feed costs during trial period.

Table 5. Phase 1 and Phase 2 (70- to 170-lb gilts) Performance Summary

	Phase 1, Lysine:Calorie Ratio (g lysine/Mcal ME)			
	2.75	3.3		
	Phase 2, Lysine:Calorie Ratio (g lysine/Mcal ME)			
	2.25	2.75		
	Estimated Requirement Status			
Item, day 0 to 55	Deficient	Optimum	SEM	Probability (P<)
ADG, lb	1.74	1.82	0.016	0.0001
ADFI, lb	3.90	3.91	0.04	0.80
F/G	2.24	2.14	0.010	0.0001
Feed cost / lb, $	0.132	0.135	0.001	0.001
IOMFC, $/hd[b]	23.73	24.54	0.25	0.004

[a]A total of 1154 gilts (PIC L337 * C22) housed at the rate of 27 to 28 pigs/pen and 21 replications per treatment in phase 1 and phase 2 (d 0 to 55) were used to evaluate effects of feeding less than (deficient) or at (optimum) the estimated lysine:calorie ratio (g lysine:Mcal ME) for optimal growth and efficiency.

[b]Income over marginal feed costs = Value of gain on a $40/CWT live weight basis - feed costs during trial period.

Table 6. Effects of Feeding Less Than, At, or More Than the Estimated Lysine Requirement in 170- to 255-lb Gilts[a]

	Phases 1 and 2 Deficient Lysine			Phases 1 and 2 Optimum Lysine								
	Phase 3; Lysine:Calorie Ratio											
	1.75	2.25	2.75	1.75	2.25	2.75						
	Total Lysine, %											
	0.63	0.81	0.99	0.63	0.81	0.99						
	Estimated Phase 3 Requirement Status							Probability (P<)				
Item	Deficient	Opti-mum	Excess	Deficient	Optimum	Excess	SEM	Phases 1 and 2	Phase 3	Phases 1 and 2 * Phase 3	Linear Phase 3	Quad. Phase 3
Day 55 to 83												
ADG, lb	1.64	1.84	1.87	1.68	1.77	1.82	0.03	0.24	0.0001	0.18	0.0001	0.10
ADFI, lb	4.78	4.80	4.67	4.86	4.82	4.79	0.07	0.08	0.09	0.67	0.05	0.31
F/G	2.91	2.61	2.49	2.90	2.73	2.63	0.04	0.002	0.0001	0.16	0.0001	0.11
Feed cost / lb, $	0.164	0.155	0.154	0.164	0.162	0.163	0.002	0.002	0.04	0.15	0.03	0.16
IOMFC, $/hd[b]	9.91	11.60	11.86	10.21	10.83	11.07	0.29	0.049	0.0002	0.15	0.0001	0.10
Weight d 83, lb	215.0	220.6	221.6	221.8	223.6	224.5	2.80	0.0006	0.05	0.73	0.02	0.4
Day 83 to 104												
ADG, lb	1.75	1.91	1.87	1.73	1.88	1.89	0.04	0.61	0.0007	0.83	0.001	0.01
ADFI, lb	5.12	5.24	5.23	5.23	5.21	5.39	0.07	0.16	0.13	0.32	0.05	0.83
F/G	2.93	2.75	2.80	3.02	2.77	2.86	0.06	0.19	0.001	0.82	0.009	0.005
Feed cost / lb, $	0.166	0.163	0.173	0.171	0.164	0.177	0.003	0.19	0.004	0.85	0.04	0.005
IOMFC, $/hd[b]	7.93	8.74	8.15	7.62	8.55	8.06	0.29	0.32	0.012	0.92	0.23	0.006
Day 55 to 104												
ADG, lb	1.68	1.87	1.87	1.70	1.81	1.84	0.03	0.25	0.0001	0.32	0.0001	0.006
ADFI, lb	4.91	4.97	4.88	5.00	4.97	5.01	0.06	0.09	0.83	0.28	0.83	0.57
F/G	2.92	2.66	2.61	2.94	2.75	2.72	0.03	0.005	0.0001	0.32	0.0001	0.001
Feed cost / lb, $	0.165	0.158	0.161	0.166	0.162	0.168	0.0016	0.005	0.006	0.31	0.63	0.002
IOMFC, $/hd[b]	17.79	20.33	20.09	17.83	19.32	19.15	0.36	0.04	0.0001	0.31	0.0001	0.0002
Sale Weight, lb	246.3	256.0	256.1	252.8	257.0	258.1	3.07	0.0032	0.0022	0.39	0.0014	0.10

[a]A total of 1154 gilts (PIC L337 * C22) housed at the rate of 27 to 28 pigs/pen with 21 pens in each early finishing treatment were subsequently fed either less than (deficient), at (optimum), or more than (excess) the estimated lysine requirement from d 55 to slaughter (phase 3).
[b]Income over marginal feed costs = Value of gain on a $40/CWT liveweight basis - feed costs during trial period.

Table 7. Overall Performance Summary (70- to 255-lb gilts)

	Phases 1 and 2 Deficient Lysine			Phases 1 and 2 Optimum Lysine								
	Phase 3; Lysine:Calorie Ratio											
	1.75	2.25	2.75	1.75	2.25	2.75						
	Total Lysine, %											
	0.63	0.81	0.99	0.63	0.81	0.99						
	Estimated Phase 3 Requirement Status							Probability (P<)				
Item, day 0 to 104	Deficient	Optimum	Excess	Deficient	Optimum	Excess	SEM	Phases 1and 2	Phase 3	Phases 1 and 2 * Phase 3	Linear Phase 3	Quad. Phase 3
Weight d 0, lb	71.7	72.6	72.3	72.4	72.2	72.4	1.72	0.53	0.77	0.49	0.57	0.65
ADG, lb	1.72	1.79	1.81	1.76	1.82	1.84	0.02	0.004	0.001	0.85	0.0002	0.10
ADFI, lb	4.34	4.38	4.35	4.38	4.40	4.41	0.04	0.10	0.62	0.73	0.45	0.53
F/G	2.53	2.44	2.41	2.48	2.41	2.41	0.02	0.02	0.0001	0.36	0.0001	0.06
Feed cost / lb, $	0.146	0.145	0.146	0.148	0.148	0.150	0.001	0.001	0.17	0.51	0.50	0.08
Sale weight, lb	246.3	256.0	256.1	252.8	257.0	258.1	3.07	0.003	0.002	0.39	0.001	0.10
Carcass yield, %	75.2%	75.0%	75.3%	75.4%	74.8%	74.7%	0.2%	0.20	0.23	0.31	0.20	0.26
10th-rib backfat, in[b]	0.72	0.65	0.64	0.69	0.64	0.63	0.01	0.09	0.0001	0.0001	0.0001	0.0001
Loin depth, in[b]	2.21	2.26	2.25	2.20	2.27	2.26	0.01	0.88	0.0001	0.12	0.0001	0.0001
Lean, %[b]	54.42	55.64	55.75	54.96	55.84	56.04	0.16	0.14	0.0001	0.0001	0.0001	0.0001
Lean premium, $/CWT	3.32	3.93	3.87	3.61	4.05	4.08	0.13	0.21	0.0002	0.78	0.0003	0.02
Carcass weight, lb	185.35	192.03	192.83	190.56	192.12	192.69	2.56	0.03	0.05	0.32	0.02	0.32
Carcass value, $	101.32	106.11	106.44	104.70	106.39	106.79	1.46	0.04	0.004	0.26	0.002	0.13
Feed cost/pig, $	25.54	26.49	26.80	26.75	27.26	27.90	0.27	0.0003	0.0001	0.56	0.0001	0.50
IOMFC, $/hd[c]	75.78	79.62	79.64	77.95	79.13	78.86	1.28	0.62	0.03	0.26	0.02	0.13

[a]A total of 1154 gilts (PIC L337 * C22) housed at the rate of 27 to 28 pigs/pen with 21 pens in each early finishing treatment were subsequently fed either less than (deficient), at (optimum), or more than the estimated lysine requirement from d 55 to slaughter (phase 3).
[b]Adjusted to a common carcass weight for analysis.
[c]Income over marginal feed costs = Value of gain on a $40/CWT liveweight basis - feed costs during trial period.

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DETERMINING THE OPTIMAL LYSINE TO CALORIE RATIO FOR GROWTH PERFORMANCE OF 20- TO 50-LB GENETIPORC NURSERY PIGS

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Summary

Two studies were conducted to evaluate the effects of increasing dietary lysine and energy density on nursery-pig performance. Exp. 1 was organized as a combination of two simultaneous experiments, with one set of diets consisting of five treatments with increasing TID lysine (0.99, 1.07, 1.14, 1.22, and 1.30%) concentrations, and the second set of diets consisting of five treatments with increasing energy density (1342, 1406, 1471, 1535, and 1600 kcal/lb). The highest l of both lysine and energy density (1.30% and 1600 kcal/lb, respectively) were combined as one diet and used in both the lysine and energy-density titrations to give a total of 10 treatments. Pigs were randomly allotted to 8 replications with 5 pigs per pen on the basis of BW. Overall (d 0 to 21) in Exp. 1 increasing true-ileal-digestible (TID) lysine increased ADG linearly and improved feed efficiency. Although increasing energy density had no effect on ADG, ADFI decreased, which resulted in a quadratic improvement in F/G. Regression analysis of the response surface was used to predict the optimal lysine-to-calorie ratio of 3.65 to 3.71 g lysine/Mcal ME for the Gentiporc pigs used in this experiment. In Exp 2, pigs were fed diets with two different energy densities (1.34 or 1.49 Mcal ME/lb) with TID lysine-to-calorie ratios ranging from 3.1 to 4.1 g/Mcal ME. There was an energy density by TID lysine-to-calorie ratio interaction observed for ADG. Pigs fed the low-energy diets had the greatest ADG at a lysine-to-calorie ratio of 3.60. For pigs fed the high energy diets, ADG improved as the lysine-to-calorie ratio improved to 3.36 g of TID lysine/Mcal ME. There was a quadratic improvement in feed efficiency as the lysine-to-calorie ratios were increased for the pigs fed the low-energy diet, with the best F/G value observed at 3.87; but the pigs fed the high-energy diets had a linear improvement in F/G as the lysine-to-calorie ratios were increased. Although there was a linear improvement in F/G for the high-energy diet, little improvement in feed efficiency was observed when the lysine-to-calorie ratio was increased from 3.36 to 4.07. On the basis of these results, we suggest that the optimal lysine-to-calorie ratio is 3.30 to 3.87 g of TID lysine/Mcal ME for 20- to 50-lb Genetiporc pigs in these facilities.

(Key Words: Lysine, Energy, Nursery Pigs, Pigs.)

Introduction

The lysine requirement of nursery pigs weighing between 20 to 50 lb has been extensively studied and was determined to be 1.01% on a true-ileal-digestible (TID) basis. But there are many issues that can change the requirement for lysine. One such factor in the young rapidly growing pig could be the interaction between energy density and lysine in-

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take. Protein deposition in the nursery pig has been shown to be limited by feed or energy intake. Thus, the amino acid requirements must be expressed in relation to the energy density of the diet. But the design used in most experiments doesn't allow the determination of the correct requirement of lysine in relation to the energy density of the diet. Most studies titrate lysine concentration with a single energy level and then calculate a lysine-to-calorie ratio based on the energy level used in the experimental diets. By determining the requirements for lysine and energy at the same time, we should be able to determine an optimal ratio more precisely.

Therefore, our objectives in this study was to first determine an optimal lysine-to-calorie ratio for maximal growth and feed efficiency of the 20- to 50-lb pig by titrating a lysine and energy requirement simultaneously, and then validate the lysine-to-calorie ratio by titrating lysine at two energy levels.

Procedures

Experiment 1. Three hundred and sixty Gentiporc pigs were blocked by weight (initially 22.5 lb) and allotted to one of the nine diets. There were five pigs per pen and eight replicate pens per treatment. This trial was organized as a combination of two separate experiments, with one set of diets consisting of five treatments with increasing TID lysine (0.99, 1.07, 1.15, 1.22, and 1.30%), and the second set of diets consisting of five treatments with increasing energy density (1342, 1406, 1471, 1535, and 1600 kcal of ME per lb). The highest rates of both lysine and energy density (1.3% and 1600 kcal, respectively) were combined as one diet and used in both the lysine and energy-density titrations to give a total of 10 treatments. The diets containing 0.99% and 1.30% TID lysine were blended to form the other diets for the lysine titration (Table 1). The diets containing 1342 kcal and 1600 kcal were blended to form the other diets for the energy titration.

All experimental diets were based on corn-soybean meal and were fed in a meal form throughout the 21-d experiment. Pigs were housed in the Kansas State University Segregated Early Weaning facility. Each pen was 4 × 4 ft and contained one self-feeder and one nipple waterier to provide ad libitum access to feed and water. Initial temperature of the facility was 90ºF for the first 7 d after weaning, and was lowered approximately 3ºF for each subsequent weeks of the experiment. The pigs and feeders were weighed on d 7, 14, and 21 to determine ADG, ADFI, and F/G.

Experiment 2. A total of 350 Genetiporc pigs (BW of 20.7 lb) were blocked by weight and allotted to one of 10 dietary treatments. There were five pigs per pen and seven replicate pens per treatment. Pigs were housed in the Kansas State University Segregated Early Weaning Facility. Each pen was 4 × 4 ft and contained one self-feeder and one nipple waterier to provide ad libitum access to feed and water.

The experimental diets (Table 2) were formulated to contain similar lysine-to-calorie ratios, with differing energy density of the diets. Energy levels (1340 and 1490 kcal of ME per lb) were selected because they were in the linear portion of the response in F/G in Exp 1. Diets for both energy-density levels were formulated by blending different percentages of the highest and lowest lysine-to-calorie ratio diets. In the low-energy-density diets, sand partly replaced corn to avoid confounding the response with changes in energy sources. Dietary mineral and vitamin content was formulated to meet or exceed National Research Council recommendations.

Analysis of variance was used to analyze the data as a randomized complete-block design using MIXED procedures of SAS. The Least Square Difference (LSD) test was used to determine differences within energy density of the treatments ($P<0.05$).

Results and Discussion

Experiment 1. From d 0 to 21, ADG increased (linear, P<0.01), but there was no difference in ADFI, as TID lysine increased from 0.99 to 1.30%. The greatest ADG was at 1.22% TID lysine. Increasing TID lysine also improved (linear, P<0.01) F/G. Increasing the energy density from 1342 to 1600 ME in the diet had no effect on ADG, but ADFI decreased (linear, P<0.01), thus improving (quadratic, P<0.01) feed efficiency (Table 3 and 4). Average daily gain and F/G were plotted on the Y axis and TID lysine or energy density was plotted on the X axis to develop a prediction equation (Figure 1 and 2). Similar points between TID lysine and energy density for ADG and F/G were used to form a regression analysis and to determine an optimal lysine-to-calorie ratio (Table 5). Regression analysis of the response surface resulted in an estimate lysine-to-calorie ratio for ADG and F/G of 3.71 and 3.65 g TID lysine per Mcal ME, respectively.

Experiment 2. Over the entire experiment period (Table 6), there was a energy density × lysine-to-calorie ratio interaction (P<0.03) observed for ADG. Pigs fed the diets containing 1340 kcal of ME per lb had a linear and quadratic (P<0.01; P<0.06, respectively) response to the increasing lysine-to-calorie ratio, with the greatest ADG for pigs fed the diet with 3.6 g TID lysine per Mcal ME. Pigs fed the diets containing 1490 kcal of ME per lb had a quadratic (P<0.01) response to an increasing lysine-to-calorie ratio, with the optimal response at 3.36 g TID lysine per Mcal ME. Increasing energy density decreased ADFI (P<0.01) and improved (P<0.01) F/G. Increasing the lysine-to-calorie ratio also decreased (P<0.06) ADFI and improved (P<0.01) feed efficiency. Pigs fed the diets with 1340 kcal of ME per lb had improved (quadratic, P<0.01) F/G as the lysine-to-calorie ratio increased, whereas pigs fed the diets containing 1490 kcal of ME per lb tended to have decreased (linear, P<0.03) ADFI and improved (linear, P<0.01) F/G as the lysine-to-calorie ratio increased. There was an energy density × lysine-to-calorie ratio interaction (P<0.03) observed for total lysine intake. Pigs fed both energy-density diets tended to increase (linear, P<0.01) lysine intake as the lysine-to-calorie ratio increased.

The importance of determining the appropriate lysine-to-calorie ratio for different energy densities is that, as we increase or decrease the energy density or lysine content in the diet by diet manipulation, the lysine-to-calorie ratio also changes. By establishing the optimal ratio, we can balance the diets accordingly. Increasing the energy density of the diet decreased ADFI and improved feed efficiency, but there was no response in ADG. Furthermore, it seems that these pigs require approximately 10 to 11 g/d of TID lysine intake to maximize growth performance. On the basis of these results, we suggest that the optimal lysine-to-calorie ratio is 3.30 to 3.87 g of TID lysine/Mcal ME for 20- to 50-lb Genetiporc pigs in these facilities. It may be possible that in our research environment, feed intake is already high enough to maximize ADG. These findings should be further evaluated in a commercial environment (i.e., 25 pigs per pen, etc.), in which feed intakes are typically less than in university research facilities.

Table 1. Composition of Diets (As-fed Basis), Exp. 1

	TID Lysine (%)/ME (kcal)		
Item, %	0.99/1600	1.30/1600	1.30/1342
Corn	59.69	58.90	53.90
Soybean meal (46.5% CP)	31.91	31.90	31.90
Choice white grease	5.00	5.00	0.00
Sand	0.00	0.00	10.00
Monocalcium P (21% P, 18% C)	1.25	1.25	1.25
Limestone	0.90	0.90	0.90
Salt	0.35	0.35	0.35
Trace mineral premix	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25
L-threonine	0.00	0.20	0.20
Antibiotic	0.50	0.50	0.50
L-Lysine HCl	0.00	0.40	0.40
DL-methionine	0.00	0.20	0.20
Total	100.00	100.00	100.00

[a]Diets that were formulated to be 0.99/1600 lys/ME and 1.30/1600 lys/ME were blended to achieve true-ileal-digestible (TID) lysine concentrations of 0.99, 1.07, 1.15, 1.22, and 1.30%.
[b]Diets that were formulated to be 1.30/1342 lys/ME and 1.30/1600 lys/ME were blended to achieve ME rates of 1342, 1406, 1471, 1535, and 1600 kcal.

Table 2. Composition of Diets (As-fed Basis), Exp. 2

	1,340 kcal/lb[a]		1,490 kcal/lb[b]	
Item, % Lysine-to-calorie Ratio, g/Mcal	3.08	4.13	3.13	4.07
Corn	57.39	56.57	63.39	62.61
Soybean meal (46.5% CP)	29.10	29.10	33.10	33.10
Sand	10.00	10.00	0.00	0.00
Monocalcium P (21% P, 18% C)	1.35	1.35	1.35	1.35
Limestone	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35
Trace mineral premix	0.15	0.15	0.15	0.15
Vitamin premix	0.25	0.25	0.25	0.25
L-valine	0.00	0.02	0.00	0.00
L-isoleucine	0.00	0.01	0.00	0.00
L-tryptophan	0.00	0.01	0.00	0.00
L-threonine	0.00	0.19	0.00	0.19
Antibiotic	0.50	0.50	0.50	0.50
L-Lysine HCl	0.00	0.40	0.00	0.40
DL-methionine	0.01	0.20	0.01	0.20
Total	100.00	100.00	100.00	100.00

[a]Diets were formulated to contain 2.89 ME with 3.08, 3.34, 3.60, 3.87, and 4.13 lysine-to-calorie ratios.
[b]Diets were formulated to contain 3.23 ME with 3.13, 3.36, 3.60, 3.83, and 4.07 lysine-to-calorie ratios.

Table 3. The Effects of Increasing TID Lysine for Growing Pigs, Exp. 1[a]

	TID Lysine, %[b]						P-value (P <)	
Item	0.99	1.07	1.15	1.22	1.30	SE	Linear	Quadratic
Day 0 to 21								
ADG, lb	1.21	1.23	1.27	1.30	1.29	0.04	0.01	0.58
ADFI, lb	2.00	1.95	1.98	2.01	1.98	0.07	0.99	0.86
F/G	1.69	1.61	1.58	1.55	1.53	0.03	0.01	0.27

[a]Each value is the mean of eight replications with 5 pigs (initially 22.5 lb) per pen.
[b]Average energy density for increasing TID lysine % is 1598 kcal and is similar for all diets.

Table 4. The Effects of Increasing Energy Density for the Growing Pig, Exp. 1[a]

	Energy Density, kcal/lb[b]						P-value (P <)	
Item	1342	1406	1471	1535	1600	SE	Linear	Quadratic
Day 0 to 21								
ADG, lb	1.26	1.34	1.32	1.29	1.29	0.04	0.90	0.14
ADFI, lb	2.33	2.25	2.13	2.03	1.98	0.07	0.01	0.62
F/G	1.84	1.67	1.61	1.58	1.53	0.03	0.01	0.01

[a]Each value is the mean of eight replications with 5 pigs (initially 22.5 lb) per pen.
[b]Average TID lysine concentration for increasing energy level is 1.30% and is similar for all diets.

Table 5. Regression Analysis of the Response Surface[a]

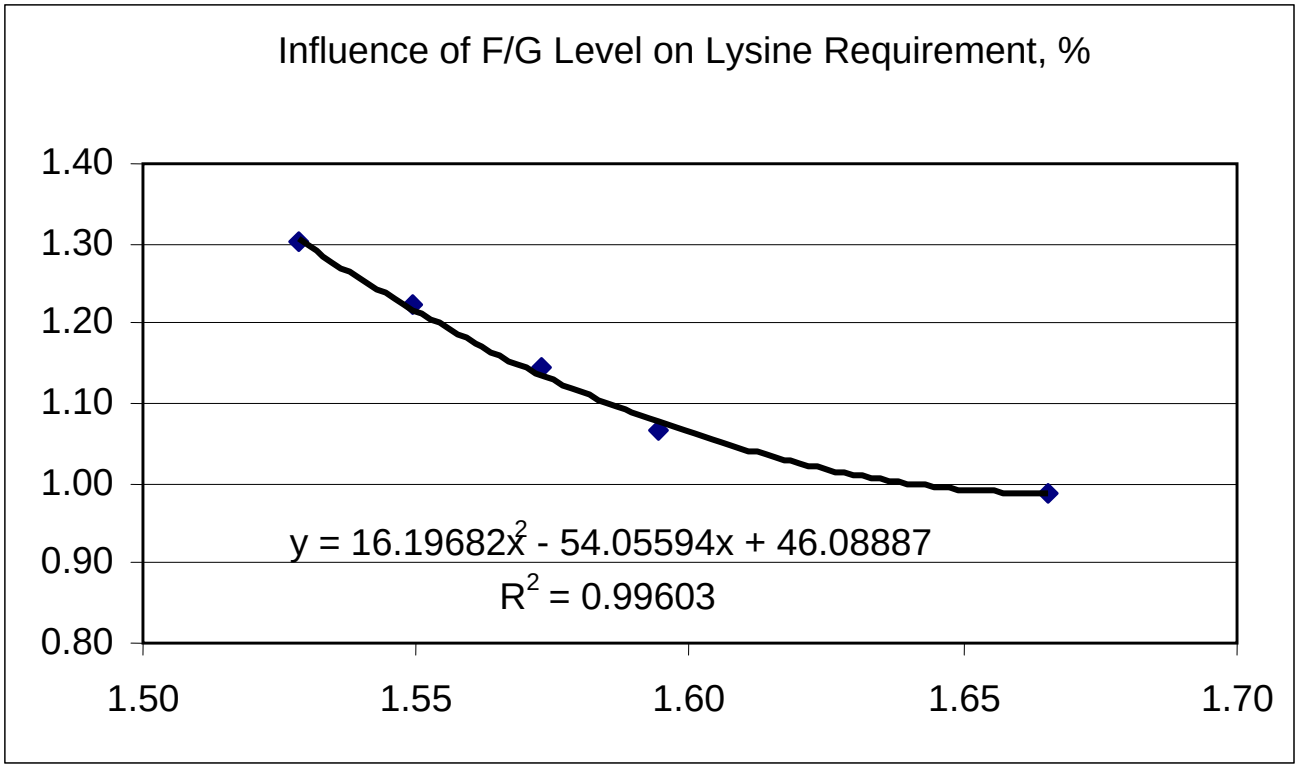
Response	TID Lysine, %	Energy Density, kcal	TID Lysine:ME, g/Mcal
F/G			
1.53	1.30	1,612	3.65
1.55	1.22	1,577	3.49
1.60	1.06	1,502	3.21
1.67	0.99	1,421	3.15
ADG			
1.29	1.27	1,548	3.71
1.28	1.23	1,500	3.71
1.27	1.19	1,422	3.80
1.265	1.17	1,371	3.88

[a]Values for F/G and ADG were similar for pigs fed diets with increasing TID Lysine and Energy Density.

Table 6. Effects of Increasing Energy Density and Lysine-to-calorie Ratio on Pig Performance (d 0 to 21), Exp. 2[a]

ME, Mcal	Lysine/ME Ratio	ADG, lb	ADFI, lb	F/G	Total Lysine Intake, g/d
2.89	3.08	1.19	2.21	1.87	9.08
	3.34	1.23	2.19	1.77	9.80
	3.60	1.32	2.28	1.72	11.02
	3.87	1.26	2.13	1.68	11.03
	4.13	1.30	2.27	1.73	12.53
3.23	3.13	1.21	2.03	1.68	9.49
	3.36	1.31	2.07	1.56	10.37
	3.60	1.30	2.07	1.58	11.14
	3.83	1.24	1.96	1.56	11.25
	4.07	1.26	1.94	1.54	11.78
SE		0.04	0.10	0.05	0.49
		P-value (P<)			
Main Effects					
Energy		0.78	0.01	0.01	0.41
Lysine/ME		0.01	0.06	0.01	0.01
Energy × lysine/ME		0.03	0.17	0.32	0.03
2.89 ME Mcal, Lysine/ME ratio					
Linear		0.01	0.71	0.01	0.01
Quadratic		0.06	0.72	0.01	0.65
3.23 ME Mcal, Lysine/ME ratio					
Linear		0.58	0.03	0.01	0.01
Quadratic		0.01	0.15	0.11	0.10

[a]Each value is the mean of seven replications with 5 pigs (initially 20.7 lb) per pen.



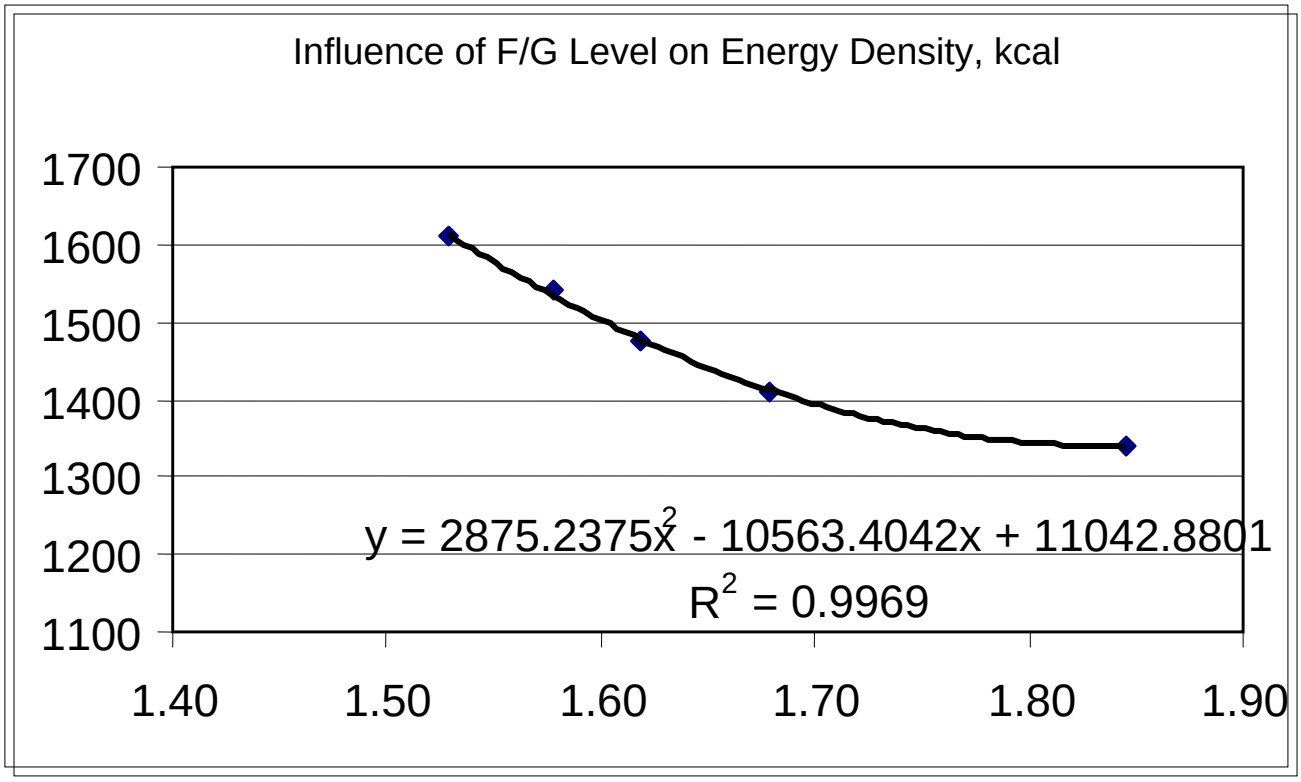
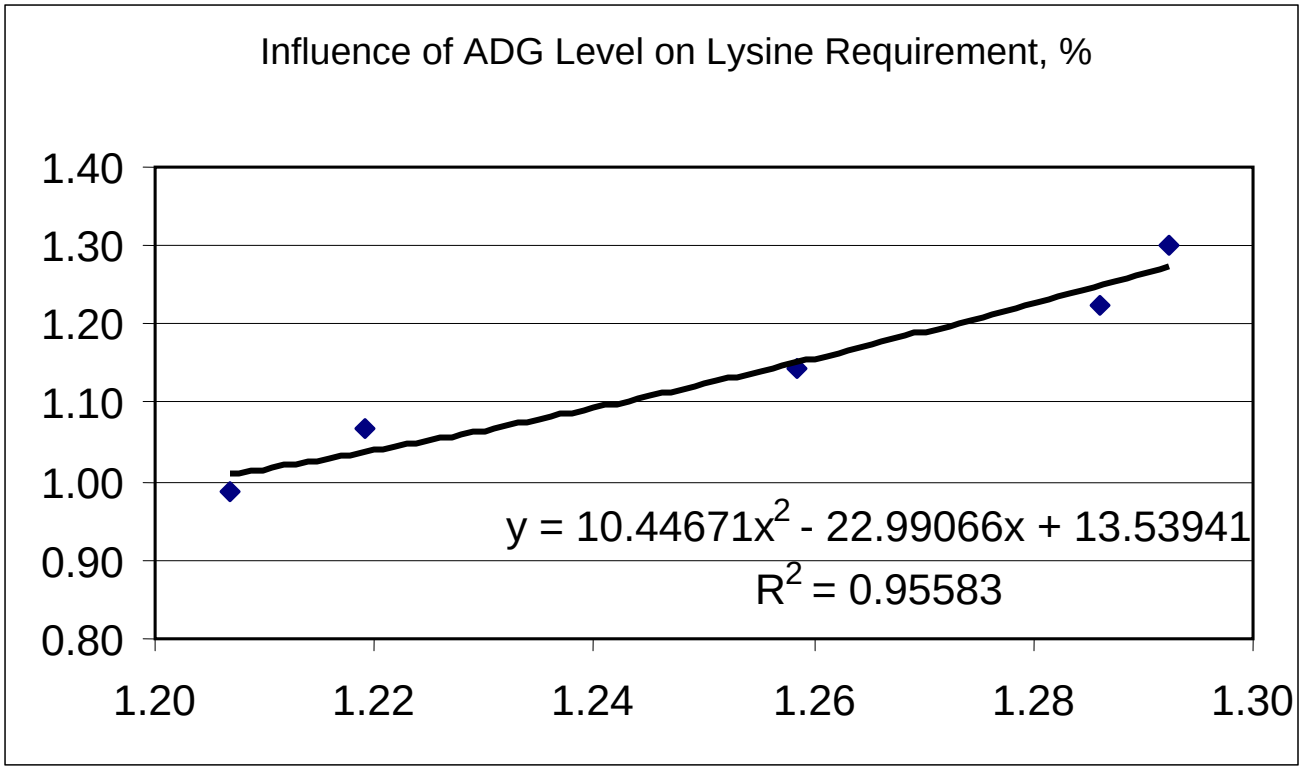


Figure 1. Regression Analysis for Lysine and Energy Density for Feed Efficiency.



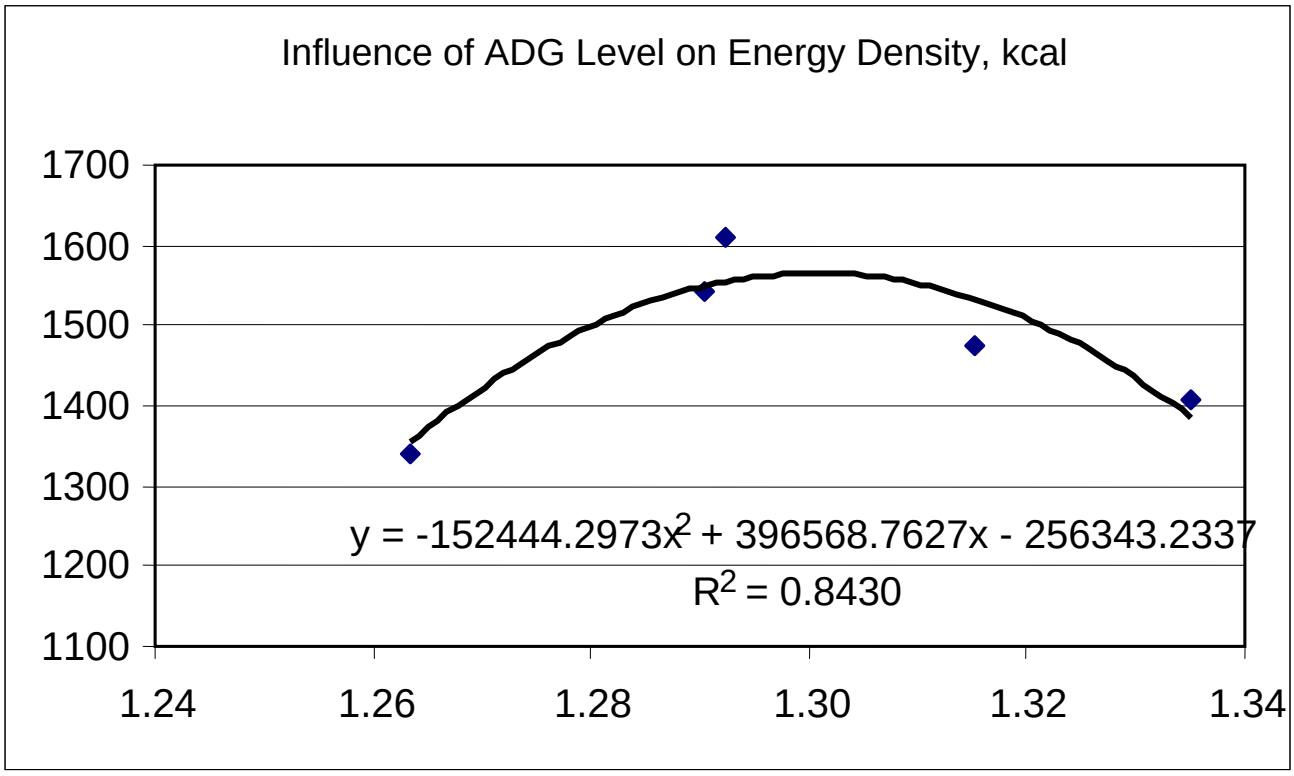


Figure 2. Regression Analysis for Lysine and Energy Density on Average Daily Gain.

EFFECTS OF INCREASING MEAT AND BONE MEAL ON FINISHING-PIG GROWTH PERFORMANCE

R. O. Gottlob, R. D. Goodband, M. D. Tokach, J. M. DeRouchey, J. L. Nelssen, S. S. Dritz[1], C. W. Hastad, K. R. Lawrence, and C. N. Groesbeck

Summary

A total of 156 finishing pigs (72 barrows and 84 gilts, initially 110 lb) were used to determine the effects on growth performance of increasing meat and bone meal. Pigs were housed in an environmentally regulated finishing building, with two pigs per pen. There were six pens of barrows and seven pens of gilts per treatment. Pigs were blocked by initial weight and sex, and then allotted to one of six dietary treatments. The dietary treatments were based on corn-soybean meal, were formulated on a true-ileal-digestible (TID) lysine basis, and were fed in three phases. In each phase, diets contained 0, 2.5, 5.0, 7.5, 10.0, or 12.5% porcine meat and bone meal. The diets were formulated to 0.85, 0.70, and 0.57% TID lysine in phases 1, 2, and 3, respectively, slightly less than the pig's anticipated requirements, so that if the amino acid digestibility of meat and bone meal was different than typical values, changes in growth performance could be observed. Increasing meat and bone meal increased ADG (quadratic, $P<0.02$), decreased ADFI (linear, $P<0.02$), and improved F/G (quadratic, $P<0.01$). Pigs fed 2.5 or 5.0% meat and bone meal had the best ADG and F/G; as meat and bone meal increased to higher concentrations, however, ADG and F/G decreased and were similar to those of pigs fed the control diet. Because the diets were formulated with slightly less than the pig's anticipated requirements, the results suggest that the meat and bone meal used was relatively high quality and contained greater digestible amino acids than expected. These results suggest that porcine meat and bone meal is a suitable replacement for soybean meal.

(Key Words: Meat and Bone Meal, Finishing Pigs, Pigs.)

Introduction

Meat and bone meal is potentially an important protein source and feed ingredient for swine because of its amino acid profile and high concentration of calcium and phosphorus. It is currently of special interest for two reasons. First, recent changes in USDA regulations regarding the use of animal by-products have resulted in dramatic fluctuations in the price of meat and bone meal. Second, high soybean-meal prices in 2004 have encouraged producers and feed manufacturers to search for alternative protein sources to keep feed costs low.

Because of possible variation in meat and bone meal composition and nutritional quality, current research is needed to evaluate the effects of feeding meat and bone meal in swine

[1]Food Animal Health and Management Center.

diets. Therefore, our objective was to evaluate the effects of increasing porcine meat and bone meal as a partial replacement for soybean meal in finishing pig diets.

Procedures

One hundred fifty-six pigs (72 barrows and 84 gilts; PIC L326 × C22) averaging 110 lb were used in this study. Pigs were housed in an environmentally regulated finishing building, with two pigs per pen and six pens (5 × 5 ft) of barrows and seven pens of gilts per treatment in a randomized complete-block design. Pigs were blocked by initial weight and sex, and then randomly allotted to one of the six dietary treatments. Feed and water were provided ad libitum.

There were six dietary treatments fed in three phases. Each phase consisted of: negative control with no meat and bone meal, and the control diet with added 2.5, 5.0, 7.5, 10.0, or 12.5% meat and bone meal. All diets were based on corn-soybean meal and were formulated on a true-ileal-digestible (TID) lysine basis. Phase 1 (110 lb to 145 lb) diets were formulated to contain 0.85% TID lysine. Phase 2 (145 lb to 211 lb) diets were formulated to contain 0.70% TID lysine. Phase 3 (211 lb to 270 lb) diets were formulated to contain 0.57% TID lysine. The experimental diets were formulated with slightly less than the pig's anticipated requirements, so that if the amino acid digestibility of meat and bone meal was different than typical values, changes in growth performance could be observed. Because meat and bone meal is relatively low in tryptophan, synthetic tryptophan was added in phase 2 and 3 diets to ensure that it would not be limiting to pig performance.

Individual pig weights were taken, and feed disappearance was measured every 14 d to calculate ADG, ADFI, and F/G. The experiment was conducted from February to April at the Kansas State University Swine Teaching and Research Center.

Several samples of porcine meat and bone meal used in the experimental diets were taken, homogenized, and sub-sampled for nutrient analysis (Table 1). In addition, the calculated values used for diet formulation are also presented in Table 1.

Results and Discussion

The meat and bone meal used had more crude protein and crude fat, but less calcium and phosphorus, than suggested NRC values (Table 1). Although crude protein concentration was higher than expected, analyzed total amino acid concentrations were only slightly higher than the NRC (1998) values used in diet formulation.

Adding 2.5 or 5.0% meat and bone meal increased ADG (quadratic, $P<0.02$), whereas feeding greater than 5.0% resulted in ADG similar to that of pigs fed the control diet. Increasing meat and bone meal also improved F/G (quadratic, $P<0.01$) over that of pigs fed the control diet, and decreased ADFI (linear, $P<0.02$). But the greatest decrease in ADFI was observed in pigs fed greater than 5.0% meat and bone meal.

The meat and bone meal used in this study seemed to be relatively high quality. The crude protein concentration was higher than anticipated, whereas calcium and phosphorus values were lower. This may reflect a slightly different ratio of muscle and fat versus bone tissue in its manufacturing. Because diets were formulated with less than the pig's requirements, the increase in ADG was possibly influenced by the amino acid digestibility of the meat and bone meal used in this trial. Replacing a portion of soybean meal with the meat and bone meal used in this experiment had no negative effect on pig performance.

Table 1. Nutrient Composition of Meat and Bone Meal (As-fed Basis)

Nutrient	Meat and Bone Meal[a]	NRC Calculated Values[b]
DM, %	94.24	93.00
CP, %	54.28	51.50
Ash, %	24.47	---
Calcium, %	7.83	9.99
Phosphorus, %	4.18	4.98
GE, kcal/lb	1,858	---
Amino Acids, %:		
Arginine	3.66	3.45
Histidine	0.97	0.91
Isoleucine	1.35	1.34
Leucine	3.06	2.98
Lysine	2.55	2.51
Methionine	0.67	0.68
Phenylalanine	1.67	1.62
Threonine	1.62	1.59
Tryptophan	0.32	0.28
Valine	2.09	2.04

[a]Values represent the means of one sample analyzed in duplicate.
[b]Typical experimental composition of meat and bone meal as listed in the National Research Council's Nutrient Requirements for Swine. These values were used in actual diet formulation.

Table 2. Phase 1 Diet Composition (As-fed Basis)[a]

	Meat and Bone Meal, %[b]					
Ingredient, %	0	2.5	5	7.5	10	12.5
Corn	75.81	76.14	76.36	75.99	75.24	74.54
Soybean meal, 46.5% CP	21.30	19.40	17.55	15.70	13.95	12.15
Meat and bone meal	---	2.50	5.00	7.50	10.00	12.50
Monocalcium phosphate, 21% P	1.05	0.50	---	---	---	---
Limestone	1.03	0.65	0.28	---	---	---
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix	0.13	0.13	0.13	0.13	0.13	0.13
Tylan 40	0.05	0.05	0.05	0.05	0.05	0.05
L-Tryptophan	---	---	---	---	---	---
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis						
Total lysine, %	0.96	0.96	0.97	0.98	0.99	0.99
TID lysine [c]	0.85	0.85	0.85	0.85	0.85	0.85
Isoleucine:lysine ratio	70	69	68	67	66	65
Leucine:lysine ratio	163	163	163	163	162	162
Methionine:lysine ratio	29	29	30	30	30	30
Met & Cys:lysine ratio	60	60	59	59	59	59
Threonine:lysine ratio	62	62	62	62	62	63
Tryptophan:lysine ratio	19	19	18	17	17	16
Valine:lysine ratio	80	81	81	81	82	82
ME, kcal/lb	1,506	1,507	1,507	1,498	1,485	1,472
Protein, %	16.3	16.8	17.2	17.6	18.0	18.4
Ca, %	0.68	0.68	0.69	0.83	1.07	1.31
P, %	0.58	0.58	0.58	0.69	0.80	0.92

[a]Diets fed in meal form.
[b]Fed to pigs from 110 lb to 145 lb.
[c]True-ileal-digestible lysine.

Table 3. Phase 2 Diet Composition (As-fed Basis)[a]

	Meat and Bone Meal, %[b]					
Ingredient, %	0	2.5	5	7.5	10	12.5
Corn	82.10	82.40	82.57	82.00	81.29	80.59
Soybean meal, 46.5% CP	15.3	13.40	11.55	9.75	7.95	6.15
Meat and bone meal	---	2.50	5.00	7.50	10.00	12.50
Monocalcium phosphate, 21% P	0.85	0.35	---	---	---	---
Limestone	1.00	0.60	0.13	---	---	---
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10	0.10	0.10
Tylan 40	0.05	0.05	0.05	0.05	0.05	0.05
L-Tryptophan	---	---	---	---	0.01	0.01
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis						
Total lysine, %	0.79	0.80	0.81	0.81	0.82	0.83
TID lysine [c]	0.70	0.70	0.70	0.70	0.70	0.70
Isoleucine:lysine ratio	69	68	67	66	65	71
Leucine:lysine ratio	178	178	179	178	177	177
Methionine:lysine ratio	31	32	32	32	33	33
Met & Cys:lysine ratio	64	64	64	64	64	63
Threonine:lysine ratio	63	63	64	64	64	64
Tryptophan:lysine ratio	19	18	17	16	16	16
Valine:lysine ratio	83	84	85	85	85	85
ME, kcal/lb	1,511	1,512	1,512	1,500	1,487	1,474
Protein, %	14.1	15.5	15.0	15.4	15.8	16.2
Ca, %	0.61	0.61	0.61	0.81	1.05	1.29
P, %	0.51	0.52	0.56	0.67	0.78	0.89

[a]All diets fed in meal form.
[b]Fed to pigs from 145 lb to 211 lb.
[c]True-ileal-digestible lysine.

Table 4. Phase 3 Diet Composition (As-fed Basis)[a]

	Meat and Bone Meal, % [b]					
Ingredient, %	0	2.5	5	7.5	10	12.5
Corn	87.49	87.79	87.86	87.18	86.48	85.77
Soybean meal, 46.5% CP	10.10	8.25	6.40	4.60	2.80	1.00
Meat and bone meal	---	2.50	5.00	7.50	10.00	12.50
Monocalcium phosphate, 21% P	0.70	0.20	---	---	---	---
Limestone	1.00	0.55	0.03	---	---	---
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08
Tylan 40	0.05	0.05	0.05	0.05	0.05	0.05
L-Tryptophan	---	---	---	0.01	0.01	0.02
Lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis						
Total lysine, %	0.65	0.66	0.66	0.67	0.68	0.69
TID lysine [c]	0.57	0.57	0.57	0.57	0.57	0.57
Isoleucine:lysine ratio	70	69	67	66	64	71
Leucine:lysine ratio	198	198	198	197	197	196
Methionine:lysine ratio	34	35	35	36	36	36
Met & Cys:lysine ratio	71	71	71	70	70	69
Threonine:lysine ratio	65	65	66	66	66	66
Tryptophan:lysine ratio	18	17	16	16	16	16
Valine:lysine ratio	87	88	89	89	90	90
ME, kcal/lb	1,516	1,516	1,515	1,502	1,489	1,476
Protein, %	12.1	12.6	13.0	13.4	13.8	14.2
Ca, %	0.56	0.56	0.56	0.79	1.03	1.28
P, %	0.46	0.47	0.54	0.65	0.76	0.87

[a]All diets fed in meal form.
[b]Fed to pigs from 211 lb to 270 lb.
[c]True-ileal-digestible lysine.

Table 5. Growth Performance of Finishing Pigs Fed Increasing Meat & Bone Meal[a]

	Meat & Bone Meal, %							Probability, P <		
Item	0	2.5	5.0	7.5	10.0	12.5	SE	Linear	Quadratic	Control vs M & B Meal
ADG, lb	2.19	2.38	2.32	2.22	2.24	2.19	.61	0.19	0.02	0.09
ADFI, lb	6.65	6.85	6.72	6.45	6.45	6.45	.14	0.02	0.73	0.61
F/G	3.03	2.88	2.90	2.92	2.90	2.95	.54	0.28	0.01	0.01

[a]A total of 156 pigs (72 barrows, 84 gilts; PIC L326 × C22; initially 110 lb), with two pigs per pen and 13 pens per treatment.

Swine Day 2004

EFFECTS OF INCREASING DRIED DISTILLER'S GRAINS ON FEED INTAKE

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Summary

Recent studies have shown that dried distiller's grains with solubles (DDGS) has an ME value similar to that of corn, but pigs fed diets with DDGS have a lesser feed intake than do those fed corn. We conducted three studies to evaluate the effects of DDGS on palatability and feed intake of growing pigs. In Exp. 1, 90 gilts (initially 58.2 lb) were used to evaluate the effects of a diet based on corn-soybean meal, alone or with 30% DDGS from two different sources, on feed preference. Source 1 DDGS was obtained from an ethanol plant built before 1990 and source 2 was obtained from a plant built after 1990. Each pen of pigs had two feeders, one with the corn-soybean meal diet and the other with one of the DDGS sources. There were 10 pens with six pigs per pen and 10 pens with 3 pigs per pen, for a total of 90 gilts; all pigs were blocked by weight. The location of the feeders was moved morning and evening each day. From d 0 to 7, there were no differences in ADFI among the dietary treatments. From d 7 to 13 and overall (d 0 to 13), however, feed intake was less ($P<0.01$) for both DDGS diets, when compared with the corn-soybean control.

In Exp. 2, 187 barrows and gilts (initially 52.1 lb) were used to examine the effects of increasing DDGS (source 2) in a 21-d preference study. Treatments consisted of a control diet based on corn-soybean meal, or the control diet with 10, 20, or 30% DDGS. There were 17 pigs per pen and 11 pens. There were four feeders in each pen, each containing a different diet, and the feeders were moved every morning and evening during the trial. During each week for the overall trial, increasing DDGS decreased (linear; $P<0.001$) ADFI.

In Exp. 3, 120 barrows and gilts (initially 41.7 lb) were used to examine the effects of Sucram®, a feed flavor additive, in corn-soybean meal diets, with and without 30% DDGS (source 2), on feed intake in a 21-d preference study. Treatments consisted of a control diet based on corn-soybean meal, or the control diet with 30% DDGS, both with or without Sucram®. There were 15 pigs per pen and 8 pens. Each pen contained all four dietary treatments in individual feeders and the feeders were moved every morning and evening during the trial. For the entire trial, adding DDGS to diets decreased ($P<0.001$) ADFI. Adding Sucram® had no effect ($P>0.33$) on feed intake in either the corn-soybean meal or DDGS diets.

These studies demonstrate that pigs prefer corn-soybean diets to diets containing DDGS. For these experiments, the source of DDGS or

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the addition of a feed flavor did not change palatability. Although it seems that the ME content of DDGS could be comparable to that of corn, palatability problems may affect pig performance, even when DDGS included at low rates in the diet.

(Key Words: Pigs, Feed Intake, DDGS.)

Introduction

Recent studies have shown that distiller's dried grains with solubles (DDGS) has higher nutrient values than previously reported by the National Research Council. These studies have shown that the ME of DDGS is similar to that of corn. A large number of new ethanol plants, which produce DDGS as a by-product, have increased the availability and feasibility for use in swine diets. Traditionally, DDGS has been fed to ruminants because it has less lysine and more fiber content than do other ingredients typically fed to pigs. New ethanol plants use advanced processing techniques and better quality control, which may lead to higher quality and a more consistent nutrient profile of DDGS than what older ethanol plants produce. Previous studies at KSU have shown that feed intake was less for pigs fed diets containing DDGS. The objective of this study was to evaluate the effects of source and rate of DDGS on feed intake in growing pigs.

Procedures

In Exp. 1, a total of 90 gilts (initially 58.2 lb) were blocked by weight and were allotted randomly to one of two dietary treatments. Treatments consisted of pens with two feeders; each pen received a diet based on corn-soybean meal, or the control diet with 30% DDGS from one of two different sources replacing corn. Source 1 DDGS was obtained from an ethanol plant built before 1990 and source 2 was obtained from a plant built after 1990 (Table 1). There were 10 pens with 3 pigs/pen and 10 pens with 6 pigs per pen, for a total of 10 pens per DDGS source. Each pen was 4 × 8 ft, with completely slatted flooring and two nipple waters. Feeder weights were measured every 7 d to determine ADFI, and pigs were weighed at the beginning and conclusion of the trial to calculate ADG and F/G. Overall ADG and F/G were 1.90 lb and 1.54 respectively. Feeder location was switched every morning and evening. This trial was conducted in the K-State Segregated Weaning Facility.

In Exp. 2, a total of 187 barrows and gilts (initially 52.1 lb) were blocked by sex in a 21-d preference study. There were 17 pigs per pen and 11 pens used in this study; each pen was 10.5 ft × 10.3 ft, with completely slatted flooring and two nipple waterers. Dietary treatments consisted of a control diet based on corn-soybean meal, or the control diet with 10, 20, or 30% DDGS from source 2 (Table 2). All four treatment diets were provided in each pen by a one-hole self feeder. Feeders were rotated clockwise one position every morning and evening. Feeder weights were taken every 7 d to determine ADFI, and pigs were weighed at the beginning and end of the trial to calculate ADG and F/G. For the overall trial, ADG and F/G were 2.13 lb and 1.83, respectively. This trial was conducted at the K-State Swine Teaching and Research Facility.

In Exp. 3, a total of 120 barrows and gilts (initially 41.7 lb) were blocked by sex in a 21-d preference study. There were 15 pigs per pen and 8 pens used in this study; each pen was 10.5 ft × 10.3 ft, with completely slatted flooring, and two nipple waterers. Treatments consisted of a control diet based on corn-soybean meal, with or without Sucram®, or the control diet with 30% DDGS (source 2; Table 3), with or without Sucram®. Sucram® is a feed flavor additive. Our objective was to see if an added flavor agent might mask the negative effects of DDGS on palatability. Each of the four treatment diets was provided in each pen with a one-hole self feeder. Feeders were rotated clockwise one position every morning and evening. Feeder weights were

taken every 7 d to determine ADFI, and pig weights were taken at the beginning and end of the trial to calculate ADG and F/G. For the overall study, ADG and F/G were 1.49 lb and 1.90, respectively. This trial was conducted at the K-State Swine Teaching and Research Center.

Results and Discussion

In Exp. 1, from d 0 to 7, there were no differences ($P>0.58$) in ADFI between the control and DDGS diets (Table 4). But feed intake was numerically less for both DDGS sources than for the control diet. From d 7 to 13 and overall (d 0 to 13), ADFI was greater ($P<0.01$) for pigs fed the control diet than for pigs fed either DDGS source.

In Exp. 2, for each week and for the overall trial, increasing DDGS decreased (linear; $P<0.001$) ADFI. The differences observed in the first week of the study were similar to those observed at the end, suggesting that pigs did not become accustomed to the DDGS and begin to eat more of this diet.

In Exp. 3, for the entire trial, adding DDGS to diets decreased ($P<0.001$) ADFI, compared with the ADFI of pigs fed control diets. There was no difference ($P<0.33$) in feed intake with the addition of Sucram® in either the control or DDGS-based diets. The addition of Sucram® does not increase feed intake when added to diets with 30% DDGS.

These studies demonstrate that the inclusion of DDGS decreased feed intake, and that pigs do not become acclimated to DDGS over time. These experiments demonstrate that pigs prefer corn-soybean diets to diets containing DDGS. Furthermore, feed intake decreased with increasing amounts of DDGS added to the diet. Regardless of DDGS source used in these trials, feed intake was decreased when DDGS was included in diets, and the addition of feed flavors did not increase palatability. Although it seems that the ME content of DDGS could be comparable to that of corn, palatability problems may affect pig performance, even when DDGS is included at low rates in the diet.

Table 1. Composition of Experiment 1 Diets (As-fed Basis)[a]

		Dried Distiller's Grains with Solubles	
Item	Control	Source 1	Source 2
Corn	57.43	28.07	28.07
Dried distiller's grains w/ solubles[b]	------	35.85	35.85
Soybean meal, 46.5% CP	35.85	3.00	3.00
Soybean oil	3.00	30.00	30.00
Monocalcium phosphate, 21% P	1.50	0.75	0.75
Limestone	1.00	1.25	1.25
Salt	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
L-Threonine	0.09	------	------
Lysine HCl	0.25	0.33	0.33
DL-Methionine	0.13	------	------
TOTAL	100.00	100.00	100.00
Calculated Analysis:			
Lysine, %	1.44	1.44	1.44
Methionine, %	0.48	0.50	0.50
Threonine, %	0.92	1.12	1.12
ME, kcal/lb	1,555	1,588	1,588
Protein, %	21.73	29.22	29.22
Ca, %	0.80	0.80	0.80
P, %	0.72	0.71	0.71
Available phosphorus, %	0.39	0.40	0.40

[a]All diets fed in meal form.
[b] Source 1was from a plant built before 1990 and source 2 was from a plant built after 1990.

Table 2. Composition of Experiment 2 Diets (As-fed Basis)[a]

		Dried Distiller Grains with Solubles,%		
Item	Control	10	20	30
Corn	60.74	52.82	45.19	37.54
Soybean meal, 46.5% CP	30.60	28.70	26.45	24.20
Choice white grease	6.00	6.00	6.00	6.00
Dried distiller's grains w/ solubles[b]	------	10.00	20.00	30.00
Monocalcium phosphate, 21% P	0.70	0.50	0.30	0.10
Limestone	0.93	0.98	1.05	1.13
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15
Antibiotic[c]	0.20	0.20	0.20	0.20
Lysine HCl	0.15	0.15	0.16	0.18
DL-Methionine	0.03	------	------	------
TOTAL	100.00	100.00	100.00	100.00
Calculated Analysis				
Lysine, %	1.20	1.20	1.20	1.20
Methionine, %	0.34	0.34	0.36	0.40
Threonine, %	0.74	0.79	0.84	0.88
ME, kcal/lb	1,632	1,647	1,662	1,677
Protein, %	19.39	20.61	21.68	22.75
Ca, %	0.60	0.60	0.60	0.60
P, %	0.53	0.53	0.53	0.52
Available phosphorus, %	0.22	0.23	0.24	0.25

[a]All diets fed in meal form.
[b] The DDGS was from source 2, a plant built after 1990.
[c] Carbodox (fed at a rate of 50g/ton).

Table 3. Composition of Experiment 3 Diets (As-fed Basis)[a]

Item	Control	Dried Distiller's Grains with Solubles
Corn	67.47	38.11
Soybean meal, 46.5% CP	30.00	30.00
Dried distiller's grains w/ solubles[b]	------	30.00
Monocalcium phosphate, 21% P	0.79	0.00
Limestone	0.92	1.18
Salt	0.35	0.35
Vitamin premix	0.15	0.15
Trace mineral premix	0.15	0.15
Lysine HCl	0.15	0.05
Sand or Sucram®	0.02	0.02
TOTAL	100.00	100.00
Calculated Analysis:		
Lysine, %	1.20	1.28
Methionine, %	0.31	34
Threonine, %	0.76	77
ME, kcal/lb	1,510	1,555
Protein, %	19.68	25.50
Calcium, %	0.62	0.62
Phosphorus, %	0.56	0.54
Available phosphorus, %	0.24	0.24

[a]All diets fed in meal form.
[b]The DDGS was from source 2, a plant built after 1990.

Table 4. Effects of Dried Distiller's Grains With Solubles (DDGS) Source on Feed Preference, Exp. 1[a]

		DDGS		
ADFI, lb/d	Control	Source 1	Source 2	SE
Day 0 to 7	1.56	1.33	1.33	0.433
Day 7 to 13	2.40[b]	0.92[c]	1.07[c]	0.445
Day 0 to 13	1.95[b]	1.14[c]	1.21[c]	0.435

[a]Mean represents a total of 90 gilts, initially 58.2 lb, given choice of corn-soybean meal diet or corn-soybean meal diet with 30% DDGS from one of two sources. Overall group ADG was 1.90 lb and F/G of 1.54.
[b,c]Means having different superscript letters within a row differ ($P<0.01$).

Table 5. Effects of Increasing Dried Distiller's Grains (DDGS) on Feed Preference, Exp. 2[a]

		DDGS, %			*P*- Value		
ADFI, lb/d	Control	10	20	30	Linear	Quadratic	SE
Day 0 to 7	1.07[b]	0.85[c]	0.75[c]	0.49[d]	0.001	0.79	0.064
Day 7 to 14	1.96[b]	1.20[c]	0.63[d]	0.22[e]	0.001	0.02	0.069
Day 14 to 21	2.10[b]	1.43[c]	0.80[d]	0.30[e]	0.001	0.24	0.070
Day 0 to 21	1.71[b]	1.16[c]	0.73[d]	0.34[e]	0.001	0.13	0.052

[a]A total of 187 pigs (17 pigs per pen and 11 pens), initially 52.1 lb, were given the choice of one of four diets in the same pen: corn-soy control or control with DDGS (Source 2) replacing corn. Overall group ADG was 2.13 lb and F/G was 1.83.
[b,c,d,e]Means having different superscript letters within a row differ ($P<0.05$).

Table 6. Effects of Dried Distiller's Grains with Solubles (DDGS) and Sucram® on Feed Preference, Exp. 3[a]

	Corn - SBM		30% DDGS		Contrast		
ADFI, lb/d	Without Sucram®	With Sucram®	Without Sucram®	With Sucram®	Corn-SBM vs DDGS	With or Without Sucram®	SE
Day 0 to 7	0.77	0.69	0.42	0.36	<0.001	0.33	0.072
Day 7 to 14	1.05	1.02	0.49	0.40	<0.001	0.43	0.070
Day 14 to 21	1.04	1.29	0.55	0.44	<0.001	0.42	0.076
Day 0 to 21	0.95	1.00	0.49	0.40	<0.001	0.71	0.059

[a]A total of 120 pigs (15 pigs per pen and 8 pens) given the choice of one of four diets in the same pen: corn-soy control with or without Sucram® and control with DDGS source 2 replacing corn, with or without Sucram®.
[b,c]Means having different superscript letters within a row differ (P<0.05).

Swine Day 2004

EFFECTS OF INCREASING PANTOTHENIC ACID ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISH PIGS REARED IN A COMMERCIAL ENVIRONMENT

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Summary

A total of 1080 pigs (PIC), initially 89.0 ± 5.1 lb were used to determine the effects of increasing pantothenic acid on growth performance and carcass characteristics of grow-finish pigs. Pigs were blocked by weight and gender, and were randomly allotted to treatment. Pigs were fed, in meal form, the experimental corn-soybean meal, added-fat diets in four phases. Dietary treatments consisted of a control diet (no added pantothenic acid), or the control diet with 22.5, 45.0, or 90.0 ppm added pantothenic acid from d-calcium pantothenate. Dietary treatments were fed from d 0 to 98 (89.0 to 272.5 lb). The first three dietary phases contained 5% choice white grease, and all diets contained 0.15% L-lysine HCl, trace mineral premix, and a standard vitamin premix manufactured with no pantothenic acid. Vitamins in the vitamin premix were supplemented at 300% of NRC guidelines. Added pantothenic acid had no effect on ADG, ADFI, or F/G, regardless of rate, and no significant differences were observed in carcass traits, including hot-carcass weight, dressing percentage, fat-free-lean index (FFLI), average backfat, and loin depth. In our experiment, added pantothenic acid did not influence growth performance or carcass composition of pigs reared in a commercial environment.

(Key Words: Pantothenic Acid, Vitamin, Pigs.)

Introduction

Pantothenic acid is one of four major B vitamins (riboflavin, niacin, thiamine) that are responsible for several metabolic and regulatory functions. Pantothenic acid is active in oxidation and acetylation reactions, the citric-acid cycle, fatty-acid synthesis, and cholesterol synthesis in the form of coenzyme A (CoA) and the acyl carrier protein (ACP). These processes are essential to maximize weight gain and efficiency. The National Research Council estimates that growing-finishing pigs have a pantothenic acid requirement of 6.0 to 10.5 ppm, and a typical corn-soybean meal diet will supply between 8.0 and 10.0 ppm pantothenic acid to the pig. Pantothenic acid in corn and soybean meal is approximately 100% bioavailable to the pig. There is evidence that increasing pantothenic acid may improve carcass leanness in pigs. Research conducted at Iowa State University showed that increasing dietary pantothenic acid (0 to 120 ppm added pantothenic acid) reduced subcutaneous fat thickness and increased loin eye area. Carcass lean content was increased by >1% for pigs fed 45 ppm

[1]Appreciation is expressed to DSM (Parsippany, NJ) for providing the vitamin premix used in this experiment.

[2]Food Animal Health and Management Center.

pantothenic acid. Additional industry research showed no improvement in loin eye area and only a numerical improvement in tenth-rib fat depth in pigs supplemented with pantothenic acid. Therefore, the objective of our studies was to further evaluate the effects of increasing pantothenic acid on pig performance and carcass composition and to determine the interactive effects of ractopamine HCl (RAC) and pantothenic acid in grow-finish pigs.

Procedures

A total of 1080 pigs (PIC) with initial BW 89.0 ± 5.1 lb were used to evaluate the effects of pantothenic acid on growing-finishing pigs reared on a commercial research site. There were 16 pens of gilts and 24 pens of barrows, with 27 pigs per pen; pens were blocked by average initial pen weight and then randomly allotted to one of four dietary treatments, with 10 pens per treatment. Pigs had ad libitum access to feed and water. Pigs were housed on totally slatted concrete floors in 6 × 6 m pens. Pigs were fed, in meal form, the experimental corn-soybean meal, added-fat diets in four phases (Table 1). Dietary treatments consisted of a control diet (no added pantothenic acid), or the control diet with 22.5, 45.0, or 90.0 ppm added pantothenic acid from d-calcium pantothenate. Dietary treatments were fed from d 0 to 98 (40.4 to 123.6 kg). The first three dietary phases contained 5% choice white grease, and all diets contained 0.15% L-lysine HCl, trace mineral premix, and a standard vitamin premix manufactured with no pantothenic acid. Pantothenic acid was added at amounts indicated by dietary treatment. Before the diets were manufactured, a pantothenic premix was prepared with d-calcium pantothenate and corn to equal 6 lb. Corn added to the premix was subtracted from the bulk-ingredient addition. The pantothenic acid premix was added to the diet during the micro-ingredient addition. Pigs were weighed, and feed disappearance was measured every 14 d to calculate ADG, ADFI, and G/F. At the conclusion of the growth study, all pigs in each pen were tattooed to maintain pen identity and were transported to a commercial packing facility (Swift, Worthington, MN) where carcass measurements were obtained from the packing facility. Individual pig data was received for hot-carcass weight, average backfat, longissimus-muscle depth, and FFLI. The data were then sorted by pen, and a pen average was generated.

Data from this experiment were analyzed as a spit-plot design, with gender as the whole plot and dietary pantothenic acid as the subplot. Pigs were blocked by weight, and analysis was performed by using the MIXED procedure in SAS. The model included contrasts for linear and quadratic effects of increasing pantothenic acid.

Results and Discussion

There were no pantothenic acid × gender interactions ($P<0.05$) observed, and there were no differences in ADG, ADFI, or G/F with added pantothenic acid, regardless of rate (Table 2). Barrows had greater ADG ($P<0.01$) and ADFI ($P<0.001$) than did gilts.

Dressing percentage, hot-carcass weight, average backfat, FFLI, and longissimus-muscle depth were measured at a commercial packing facility. There were no ($P<0.05$) effects on carcass traits with increasing rates of added pantothenic acid (Table 2); there was, however, a tendency ($P<0.08$) toward a quadratic effect of dressing percentage and hot-carcass weight. Dressing percentage decreased numerically through 22.5 ppm added pantothenic acid, and hot-carcass weight decreased numerically through 45.0 ppm added pantothenic acid. Gilts had less ($P<0.001$) backfat and a higher ($P<0.001$) FFLI than barrows had. Gilts had less ($P<0.001$) average backfat than barrows had. There were no

(P>0.10) gender differences observed in dressing percentage or loin depth.

Adding dietary pantothenic acid to diets during the growing-finishing phase did not improve growth performance or carcass composition of commercially reared finishing pigs.

Table 1. Ingredient and Chemical Composition of Diets (As-Fed Basis)[a]

Item	Phase 1	Phase 2	Phase 3	Phase 4
Ingredient, %				
Corn[b]	61.62	67.22	72.74	81.53
Soybean meal (46.5% CP)	30.53	25.08	19.63	15.57
Choice white grease	5.00	5.00	5.00	-
Monocalcium phosphate (21% P)	1.05	0.90	0.83	1.10
Limestone	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35
Vitamin premix[c]	0.15	0.15	0.15	0.15
Trace mineral premix[d]	0.15	0.15	0.15	0.15
L-Lysine HCl	0.15	0.15	0.15	0.15
	100.00	100.00	100.00	100.00
Calculated Analysis				
Total lysine, %	1.20	1.05	0.90	0.80
ME, kcal/lb	1608	1611	1613	1507
CP, %	19.4	17.4	15.3	14.2
Ca, %	0.70	0.65	0.62	0.66
P, %	0.60	0.55	0.51	0.57
Available P, %	0.29	0.26	0.23	0.29
Lysine:calorie ratio, g/Mcal	3.39	2.96	2.53	2.41

[a]Dietary treatments were fed in four phase feeding periods, d 0 to 28, 29 to 56, 57 to 70, and 71 to 98, respectively. Analyzed pantothenic acid amounts of 12.7, 10.2, 10.6, and 11.1 ppm in the basal diet.

[b]Corn was replaced with d-calcium pantothenate, resulting in four dietary treatments (0, 22.5, 45, and 90 ppm added pantothenic acid).

[c]Provided (per lb of diet): 3,000 IU of vitamin A; 450 IU of vitamin D_3; 12 IU of vitamin E; 1.20 mg of vitamin K (as menadione sodium bisulfate); 15 mg niacin; 2.7 mg of riboflavin; and 0.011 mg of B_{12}.

[d]Provided (per lb of the diet): 18 mg of Mn (oxide); 78 mg of Fe (sulfate); 75 mg of Zn (oxide); 8 mg of Cu (sulfate); 0.14 mg of I (as Ca iodate); and 0.14 mg of Se (as Na selenite).

Table 2. Effects of Increasing Dietary Pantothenic Acid (PA) on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs[ab]

	Added Pantothenic Acid, ppm					Probability, P <			
Item	0.0	22.5	45.0	90.0	SE	PA	Linear	Quadratic	Gender
D 0 to 98									
Initial wt, lb	88.54	88.85	88.86	88.07	1.69	0.61	0.51	0.25	0.29
ADG, lb	1.88	1.86	1.88	1.91	0.02	0.45	0.24	0.27	0.01
ADFI, lb	5.15	5.14	5.16	5.23	0.05	0.62	0.26	0.48	0.001
F/G	2.75	2.76	2.75	2.73	0.03	0.89	0.92	0.47	0.01
Final wt, lb	271.33	270.16	269.68	272.77	2.27	0.77	0.78	0.46	0.01
Carcass measurements									
Dressing percentage	75.46	74.54	75.08	74.97	0.30	0.07	0.34	0.08	0.45
Hot-carcass wt, lb	205.81	203.74	201.66	205.69	1.51	0.19	0.72	0.07	0.001
Tenth-rib backfat, in	0.68	0.69	0.70	0.69	0.02	0.71	0.39	0.94	0.001
FFLI	50.42	50.36	50.05	50.29	0.19	0.38	0.32	0.37	0.001
Longissimus muscle depth, in	2.30	2.33	2.27	2.27	0.05	0.26	0.20	0.26	0.64

[a]A total of 1080 pigs (PIC, initial BW 89.0 ± 5.1 lb), were used in the experiment. The values represent the mean of 27 pigs per pen and 10 pens per treatment.
[b]There were no PA × Gender interactions, P<0.05, observed.

Swine Day 2004

INTERACTIVE EFFECTS BETWEEN PANTOTHENIC ACID AND RACTOPAMINE HCl (PAYLEAN®) ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROWING-FINISHING PIGS[1]

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Summary

Two experiments were conducted to evaluate the interactive effects between added pantothenic acid and ractopamine HCl (Paylean®) on growth performance and carcass traits of growing-finishing pigs. In Exp. 1, 156 pigs (PIC, initial BW = 56.7 ± 5.8 lb) were used in a 2 × 3 factorial with ractopamine HCl (RAC; 0 or 10 ppm) and added pantothenic acid (PA; 0, 22.5, or 45 ppm). Pigs were fed the assigned PA concentrations from 56.7 to 268.1 lb (d 0 to 98), and were fed RAC for the last 28 d before slaughter. Increasing added PA had no effect (P<0.05) on ADG, ADFI, or feed efficiency (F/G) from d 0 to d 70. A PA × gender interaction (P<0.05) was observed for ADG and F/G from d 71 to 98. Increasing PA increased ADG and F/G in gilts, but not in barrows. Added RAC for the last 28 d before slaughter increased (P<0.001) ADG and F/G for d 71 to 98 and d 0 to 98. Increasing the amount of added PA had no effect (P<0.05) on carcass traits. Adding RAC increased (P<0.001) longissimus muscle area and percentage lean. In Exp. 2, the effects of added PA on N balance of finishing pigs fed RAC were evaluated. A total of 156 barrows (PIC, initial weight = 131.6 lb) were fed added PA (0, 22.5, or 45.0 ppm) for a minimum of eight weeks. A total of 44 pigs were randomly selected from the 156 initial pigs and were moved into individual stainless-steel metabolism creates. Pigs remained on their respective PA treatments, with or without RAC (10 ppm), for 8 d, were moved out of the collection chambers, and were fed the same diets from d 8 to 28. There were no PA × RAC interactions (P<0.05) observed. Added PA had no effect (P<0.05) on N excretion, N retention, or biological value (BV). Fecal N excretion was greater (P<0.01) for pigs fed RAC, compared with that of the pigs not fed RAC, but urinary N decreased (P<0.01) for the pigs fed RAC, resulting in no difference in total excreted N. Adding RAC increased (P<0.04) BV. No PA (P < 0.05) response was observed for ADG or F/G, and RAC increased (P<0.001) ADG and F/G from d 0 to 28.

(Key Words: Growth, Pantothenic Acid, Pigs, Ractopamine HCl, Vitamin.)

Introduction

Pantothenic acid is one of four major B vitamins (riboflavin, niacin, thiamine) that are responsible for several metabolic and regulatory functions. Pantothenic acid is active in oxidation and acetylation reactions, the citric-acid cycle, fatty-acid synthesis, and cholesterol synthesis in the form of coenzyme A

[1]Appreciation is expressed to DSM (Parsippany, NJ) for providing the vitamin premix used in this experiment.

[2]Food Animal Health and Management Center.

(CoA) and the acyl carrier protein (ACP). These processes are essential to maximize weight gain and efficiency. The National Research Council estimates that growing-finishing pigs have a pantothenic acid requirement of 6.0 to 10.5 ppm, and a typical corn-soybean meal diet will supply between 8.0 and 10.0 ppm pantothenic acid to the pig. Pantothenic acid in corn and soybean meal is approximately 100% bioavailable to the pig. There is evidence that increasing pantothenic acid may improve carcass leanness in pigs. Research conducted at Iowa State University showed that increasing dietary pantothenic acid (0 to 120 ppm added pantothenic acid) reduced subcutaneous fat thickness and increased loin eye area. Carcass lean content was increased by <1% for pigs fed 45 ppm PA. Additional feed-industry studies showed no improvement in loin eye area and only a numerical improvement in tenth-rib fat depth in pigs given supplemental pantothenic acid. The objective of our studies was to further evaluate the effects of increasing pantothenic acid on pig performance and carcass composition and determine the interactive effects of ractopamine HCl (RAC) and pantothenic acid in growing-finishing pigs.

Procedures

The Kansas State University Animal Care and Use Committee approved all experimental protocols used in these experiments.

Experiment 1. A total of 156 PIC pigs (PIC, Franklyn, KY), with initial BW of 56.7 ± 5.8 lb, were used. Pigs were blocked by weight and sex, and randomly allotted to one of six dietary treatments. There were 42 pens of barrows and 36 pens of gilts, with two pigs per pen and 13 pens per treatment. Pigs had ad libitum access to feed and water. Pigs were housed on totally slatted concrete floors in 4 × 4 ft pens. Pigs were fed, in meal form, the experimental diets based on corn-soybean meal in four phases (Table 1). Dietary treatments consisted of a control diet (no added pantothenic acid), or the control diet with 22.5 or 45.0 ppm added pantothenic acid from d-calcium pantothenate. Ractopamine HCl (RAC; 0 or 10 ppm; Elanco, Indianapolis, IN) was fed the last 28 d before slaughter. Dietary treatments were fed from d 0 to market (56.7 to 268.1 lb). All diets contained 0.15% L-lysine HCl. The vitamin premix contained no pantothenic acid and was formulated to provide approximately 300% of the National Research Council's estimate for niacin, riboflavin, B_{12}, and vitamins A, D, E, and K. A pantothenic acid premix was prepared with d-calcium pantothenate, corn starch, and corn to equal 6 lb. Corn added to the premix was subtracted from the bulk ingredient addition. The pantothenic acid premix was added to the diet during the micro-ingredient addition.

Pigs and feeders were weighed every 14 d to calculate ADG, ADFI, and F/G. At the conclusion of the growth study, all pigs in each pen were tattooed to maintain individual pig identity and were transported to a commercial packing facility (R. C. Pork, Downs, KS). Hot-carcass weight was measured at the packing facility. Carcasses were chilled for 6 h and then backfat was measured with a ruler at the first and last rib and last lumbar vertebrae. Longissimus muscle area and tenth-rib backfat were traced onto acetate paper and measured on the left side of all carcasses.

Experiment 2. A total of 156 barrows, initially 131.6 lb, were used in the selection process for the 44 pigs used in Exp. 2. The 156 pigs were fed in two groups of 78 pigs, with 13 pigs per pen and 2 pens per dietary treatment. Pigs had ad libitum access to feed and water, and were housed in 6 × 15 ft pens with partly slatted concrete floors. Pigs were fed, in meal form, the experimental acclimation diet based on corn-soybean meal for at least eight weeks (Table 1) The acclimation diet was identical to the phase 4 diet without RAC used in Exp.1, with dietary treatments consisting of a control diet (no added pantothenic acid), or the control diet with 22.5 or

45.0 ppm added pantothenic acid from d-calcium pantothenate. As in Exp. 1, a 6-lb pantothenic acid premix (d-calcium pantothenate, corn starch, and corn) was prepared before manufacturing diets, and was added to the diet during micro-ingredient addition.

Twelve pigs were selected with an average weight of 207.3 lb at the end of eight weeks and were moved to individual, stainless-steel metabolism crates (2 × 5 ft) designed for separate collection of feces and urine. Each pig was immediately fed the original corresponding pantothenic acid concentration, with or without ractopamine HCl (RAC; 0 or 10 ppm) on d 0, resulting in two pigs per dietary treatment. Each pig was allowed three d (d 0 to 3) to adapt to the dietary treatments, then total fecal and urine were collected (d 3 to 6). Ferric oxide (1% of the diet) was used as an indigestible marker to identify the beginning and end of the fecal collection period. It was added to the first meal of the collection period (d 3), and the fecal collection began with the appearance of marked feces. The marker was also added to the seventh meal, and fecal collection stopped with the appearance of marked feces. Feces were collected twice daily, the weight was recorded, and the feces were pooled for each pig, and stored at -20°C for later analysis. Feces were dried at 55°C and ground through a Wily mill. After grinding, a subsample was collected for analysis of DM and N. Urine was collected into plastic bottles containing 25 mL of 6 *N* HCl. Urine volume was recorded, and 10% of the daily collection was stored at -20°C, for later analysis for DM and N. Feces and urine were analyzed for GE by using adiabatic bomb calorimetery. Data was used to calculate GE, DE, ME, N intake, fecal and urinary N, N retention, percentage of N retention, and biological value. Pigs were initially fed 3% of body weight, increasing the percentage fed to maximize feed intake until the start of the collection period, at which time feed intake was held constant. Feed was divided into two equal meals and fed at 5:30 a.m. and 5:30 p.m. each day; pigs were allowed ad libitum access to water. Pigs were removed from the metabolism chambers on d 8 and were fed the same treatment diets for an additional 20 d, for a total of 28 d on treatment diets. A second set of twelve pigs were removed from the original group of 78 pigs and moved to the metabolism chambers according to the same protocol. Because of the rapid changes in protein deposition in pigs fed RAC, we performed the replication with four sets of new pigs, for a total of 44 pigs. On d 28 of the treatment diets, pigs were weighed, tattooed to maintain pig identity, and transported to the KSU Meats Lab. Hot-carcass weight and leaf fat were collected at time of harvest. Cold-carcass weight and backfat were measured 24 hours after harvest. Longissimus muscle area and tenth-rib backfat were traced from the left side of all carcasses. Color, marbling, and firmness were visually scored according to NPPC specifications. A one-inch core sample was removed from each carcass loin for drip-loss analysis.

Statistical Analyses. Analysis was performed by using MIXED procedure in SAS v. 8.1. Pigs were blocked by weight and gender in Exp. 1 and by weight in Exp. 2. Data in Exp. 1 and 2 were analyzed as a 2 × 3 factorial. The model statements included contrasts for linear and quadratic effects of increasing pantothenic acid.

Results

Experiment 1. From d 0 to 70, increasing added pantothenic acid had no effect ($P<0.05$) on ADG, ADFI, or F/G (Table 2). As expected, barrows had a greater ADG ($P<0.001$) and ADFI ($P<0.01$) than gilts had. When RAC was fed (d 71 to 98), there was no pantothenic acid × RAC × gender or pantothenic acid × RAC interactions ($P<0.05$) observed. But a pantothenic acid × gender interaction ($P>0.05$) was observed for ADG and F/G. Increasing the amount of added pantothenic acid increased ADG and F/G in gilts, but not in barrows. The response observed d 71 to 98 re-

sulted in a similar response for the overall feeding period (d 0 to 98). Average daily gain and F/G increased with pantothenic acid addition in gilts, but no differences were observed for ADG and F/G in barrows (Table 3). Adding RAC increased (P<0.001) ADG and improved (P<0.001) F/G from d 71 to 98 and for the overall feeding period (Table 2). Pigs fed the RAC treatments had a greater (P<0.01) final weight than pigs fed diets containing no RAC.

There were no pantothenic acid × RAC or RAC × gender interactions observed for carcass traits. Increasing the amount of added pantothenic acid had no effect (P<0.05) on carcass traits (Table 4). Adding RAC increased (P<0.001) longissimus area and percentage lean and decreased (P<0.02) tenth-rib and last-lumbar fat depth (Table 4). Gilts had a greater (P<0.01) dressing percentage and percentage lean than barrows had. Gilts also had less (P<0.01) average backfat and a tendency toward having a smaller (P<0.06) loin eye area than barrows did.

Experiment 2. There were no pantothenic acid × RAC interactions (P<0.05) observed. There was no pantothenic acid (P<0.05) response of ADG or F/G. (Table 5). Ractopamine HCl improved (P<0.001) ADG and F/G from d 0 to 8, 8 to 28, and for the overall feeding period, and pigs in RAC treatments also had a greater (P<0.001) final weight than did pigs fed dietary treatments containing no RAC. In Exp. 1, there was a 16% improvement in ADG, with approximately a 6.5-lb increase in final weight, compared with the weight of pigs fed the non-RAC dietary treatment. An 11% improvement in F/G was also observed in pigs fed the RAC dietary treatments, compared with the F/G of pigs fed the non-RAC dietary treatments in Exp. 1. In Exp. 2, there was approximately an 11-lb improvement in final weight, compared with the weight of pigs fed the non-RAC dietary treatments. With the increase in growth performance for pigs fed RAC, N retention and BV are expected to increase.

In Exp. 2, added pantothenic acid had no effect (P<0.05) on N excretion, N retention, or BV%, but fecal N excretion was greater (P<0.01) for the pigs fed RAC, compared with that of pigs fed the diets containing no RAC, and urinary N decreased (P<0.01) for the pigs fed RAC, resulting in no significant difference in total excreted N. But the pigs fed the RAC dietary treatments did have a numerically lower value for total N excreted. Adding RAC increased (P<0.04) BV and numerically increased (P<0.07) N retained as a percentage of N intake.

There were no pantothenic acid × RAC interactions (P<0.05) observed for carcass traits. Increasing pantothenic acid had no effect (P<0.05) on carcass traits (Table 6), but there was a linear effect (P<0.04) observed for hot-carcass weight and cold-carcass weight as the amount of added pantothenic acid increased. Adding RAC increased (P<0.001) hot-carcass weight and cold-carcass weight. Leaf fat decreased (P<0.04) with the addition of RAC, and RAC also had a tendency (P<0.06) to increase drip loss, compared with that of pigs not fed RAC.

Our data suggest that adding increasing amounts of pantothenic acid to diets during the growing-finishing phase does not provide any consistent advantage in growth performance or carcass composition of finishing pigs. Adding RAC improves ADG, F/G, and percentage lean.

Table 1. Ingredient and Chemical Composition of Diets (Exp. 1, and 2; As-fed Basis)[a]

Item	Phase 1	Phase 2	Phase 3	Phase 4[b]
Ingredient, %				
Corn	67.41	72.74	78.12	74.49
Soybean meal (46.5% CP)	30.03	24.60	19.17	22.80
Monocalcium phosphate (21% P)	0.75	0.85	0.90	0.85
Limestone	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35
Vitamin premix[c]	0.15	0.15	0.15	0.15
Trace mineral premix[d]	0.15	0.15	0.15	0.15
Corn starch[e]	0.01	0.01	0.01	0.06
L-Lysine HCl	0.15	0.15	0.15	0.15
	100.00	100.00	100.00	100.00
Calculated Analysis				
Total lysine, %	1.20	1.05	0.90	1.00
ME, kcal/lb	1,509	1,509	1,509	1,508
CP, %	19.7	17.6	15.6	16.9
Ca, %	0.64	0.64	0.64	0.64
P, %	0.55	0.55	0.54	0.54
Available P, %	0.23	0.25	0.25	0.24
Lysine:calorie ratio, g/Mcal	0.31	0.32	0.33	0.32

[a]Exp. 1, dietary treatments were fed in four phases, d 0 to 28, 29 to 56, 57 to 70, and 71 to 98, with analyzed pantothenic acid concentrations of 12.5, 10.1, 8.75, and 8.12 ppm, respectively, in the basal diets.

[b]Exp. 2, dietary treatments were fed for an eight-week acclimation period, and then RAC was added at 0 or 10 ppm for 28 d, with analyzed pantothenic acid concentrations of 8.63 and 8.02 ppm, respectively.

[c]Provided (per lb of diet): 3,000 IU of vitamin A; 450 IU of vitamin D_3; 12 IU of vitamin E; 1.20 mg of vitamin K (as menadione sodium bisulfate); 15 mg niacin; 2.7 mg of riboflavin; and 0.011 mg of B_{12}.

[d]Provided (per lb of the diet): 18 mg of Mn (oxide), 78 mg of Fe (sulfate), 75 mg of Zn (oxide), 8 mg of Cu (sulfate), 0.14 mg of I (as Ca iodate), and 0.14 mg of Se (as Na selenite).

[e]Corn starch was replaced with d-calcium pantothenate, resulting in three dietary treatments (0.0, 22.5, and 45.0 added pantothenic acid). RAC replaced corn starch in phase 4 to provide 10 ppm.

Table 2. Effects of Increasing Dietary Pantothenic Acid (PA) on Growth Performance of Finishing Pigs Fed Ractopamine HCl (RAC), Exp. 1 (As-fed Basis)[a]

	RAC, ppm													
	0.0			10.0										
	Added Pantothenic Acid, ppm							Probability, P <						
Item	0.0	22.5	45.0	0.0	22.5	45.0	SE	PA	Linear	Quadratic	RAC	Gender	RAC X PA	PA X Gender
Day 0 to 70														
Initial wt, lb	55.63	55.59	55.60	---	---	---	1.68	0.69	0.57	0.52	---	0.57	---	0.18
ADG, lb	2.12	2.12	2.09	---	---	---	0.02	0.43	0.25	0.54	---	0.0001	---	0.79
ADFI, lb	5.16	5.12	5.04	---	---	---	0.08	0.41	0.19	0.80	---	0.01	---	0.45
F/G	2.44	2.42	2.42	---	---	---	0.03	0.79	0.51	0.84	---	0.68	---	0.22
Day 71 to 98														
Day 70 wt, lb	208.44	205.30	204.10	203.40	204.44	201.37	3.03	0.29	0.12	0.76	0.09	0.01	0.59	0.85
ADG, lb	2.04	2.05	2.08	2.44	2.44	2.49	0.07	0.74	0.51	0.68	0.001	0.25	0.99	0.01
ADFI, lb	6.54	6.44	6.28	6.45	6.18	6.52	0.16	0.50	0.53	0.32	0.82	0.01	0.22	0.24
F/G	3.22	3.03	2.95	2.69	2.64	2.70	0.08	0.20	0.09	0.51	0.001	0.14	0.16	0.03
Day 0 to 98														
Final wt, lb	264.85	262.68	262.35	271.79	272.63	270.97	3.93	0.84	0.56	0.95	0.01	0.01	0.87	0.14
ADG, lb	2.13	2.10	2.10	2.17	2.20	2.19	0.03	0.93	0.81	0.76	0.001	0.001	0.59	0.21
ADFI, lb	5.63	5.53	5.44	5.44	5.39	5.42	0.08	0.49	0.25	0.80	0.13	0.01	0.63	0.72
F/G	2.65	2.63	2.59	2.50	2.45	2.48	0.04	0.26	0.13	0.55	0.001	0.66	0.58	0.02

[a]A total of 156 pigs (PIC, initial BW = 56.7 ± 5.8 lb) were used in the experiment. The values represent two pigs per pen and 13 pens per treatment.

Table 3. Effects of Increasing Dietary Pantothenic Acid (PA) on Growth Performance of Barrows and Gilts Fed Ractopamine HCl (RAC), Exp. 1 (As-fed Basis)[a]

	Gender							
	Barrow				Gilt			
	Added Pantothenic Acid, ppm							
Item	0.0	22.5	45.0	SE	0.0	22.5	45.0	SE
Day 71 to 98								
ADG, lb[b]	2.41	2.25	2.26	0.07	0.94	1.01	1.04	0.04
ADFI, lb	6.89	6.44	6.69	0.18	2.77	2.80	2.76	0.08
F/G[b]	2.93	2.90	2.98	0.8	0.34	0.36	0.38	0.01
Day 0 to 98								
ADG, lb	2.25	2.23	2.20	0.03	0.93	0.94	0.95	0.02
ADFI, lb	5.73	5.66	5.69	0.11	2.42	2.39	2.34	0.06
F/G[b]	2.54	2.54	2.59	0.04	0.38	0.40	0.41	0.01

[a]A total of 156 pigs (PIC, initial BW = 56.7 ± 5.8 lb) were used in the experiment. The values represent two pigs per pen and 13 pens per treatment.
[b]Added pantothenic acid × gender interactions $P<0.05$.

Table 4. Effects of Increasing Dietary Pantothenic Acid (PA) on Carcass Characteristics of Finishing Pigs Fed Ractopamine HCL (RAC), Exp. 1[ab]

	RAC, ppm													
	0.0			10.0										
	Added Pantothenic Acid, ppm							Probability, P <						
Item	0.0	22.5	45.0	0.0	22.5	45.0	SE	PA	Linear	Quadratic	RAC	Gender	RAC PA	PA X Gender
Dressing percentage	74.86	75.93	76.13	74.11	73.06	74.35	1.50	0.79	0.56	0.74	0.09	0.01	0.71	0.09
Hot-carcass wt, lb	194.71	193.25	193.33	203.02	203.16	202.86	2.93	0.75	0.55	0.66	0.53	0.66	0.76	0.53
Backfat measurement, in														
First rib[c]	1.65	1.64	1.63	1.62	1.65	1.67	0.06	0.93	0.73	0.86	0.17	0.03	0.76	0.29
Last rib[c]	0.93	0.99	0.94	0.91	0.92	0.87	0.03	0.51	0.68	0.28	0.59	0.001	0.63	0.08
Last lumbar[c]	0.71	0.69	0.66	0.61	0.60	0.59	0.03	0.38	0.17	0.79	0.02	0.01	0.86	0.96
Avg backfat[c]	1.09	1.10	1.08	1.05	1.06	1.05	0.03	0.90	0.69	0.85	0.92	0.01	0.93	0.23
Tenth rib[c]	0.67	0.63	0.65	0.53	0.58	0.59	0.03	0.79	0.54	0.77	0.02	0.01	0.13	0.17
Percentage lean[c]	56.96	57.49	57.67	60.05	59.33	59.27	0.50	0.98	0.95	0.89	0.001	0.001	0.28	0.26
Longissimus muscle area, in[c]	8.19	8.23	8.48	9.00	8.89	8.86	0.18	0.93	0.82	0.77	0.001	0.06	0.59	0.68

[a]A total of 156 pigs (PIC, initial BW = 57.8± 5.8 lb) were used in the experiment. The values represent two pigs per pen and 13 pens per treatment.
[b]There were no PA × RAC × Gender, PA × Gender, or RAC × PA interactions observed P<0.05.
[c]Covariate with hot-carcass weight.

Table 5. Effects of Increasing Dietary Pantothenic Acid (PA) on Growth of Finishing Pigs Fed Ractopamine HCl (RAC), Exp. 2[a]

	RAC, ppm											
	0.0			10.0								
	Added Pantothenic Acid, ppm							Probability, P <				
Item	0.0	22.5	45.0	0.0	22.5	45.0	SE	PA	Linear	Quadratic	RAC	RAC X PA
Pre-feeding period (131.6 to 209.3 lb)[b]												
ADG, lb	2.20	2.18	2.20	---	---	---	0.02	0.60	0.87	0.36	---	---
ADFI, lb	6.39	6.32	6.20	---	---	---	0.09	0.49	0.23	0.74	---	---
F/G	2.90	2.90	2.82	---	---	---	0.02	0.24	0.16	0.32	---	---
Metabolism (d 0 to 8)[c]												
Initial wt, lb	209.3	212.4	209.9	205.9	208.7	210.31	12.06	0.07	0.07	0.16		
ADG, lb	2.60	2.33	2.57	3.12	3.05	3.26	0.20	0.47	0.77	0.23	0.002	0.85
ADFI, lb	6.32	6.36	6.34	6.21	6.34	6.35	0.18	0.14	0.10	0.25	0.32	0.45
F/G	2.47	3.05	2.49	2.03	2.14	2.02	0.21	0.36	0.10	0.16	0.001	0.90
Post-feeding (d 8 to 28)[d]												
Initial wt, lb	231.37	233.50	232.87	234.00	236.50	239.89	13.97	0.27	0.12	0.82	0.03	0.58
ADG, lb	1.98	2.37	2.30	2.72	2.86	2.62	0.37	0.246	0.48	0.14	0.001	0.39
ADFI, lb	6.68	7.64	6.79	6.18	7.61	6.79	0.79	0.01	0.34	0.004	0.56	0.74
F/G	3.55	3.60	3.08	2.40	2.69	2.65	0.28	0.49	0.79	0.26	0.001	0.26
Entire RAC period (d 0 to 28)												
ADG, lb	2.20	2.39	2.38	2.86	2.95	2.85	0.23	0.46	0.46	0.33	0.001	0.70
ADFI, lb	6.60	7.22	6.64	6.22	7.20	6.67	0.51	0.01	0.32	0.01	0.54	0.65
F/G	3.06	3.17	2.87	2.18	2.46	2.33	0.16	0.37	0.93	0.16	0.001	0.42
Final wt, lb	266.83	277.00	273.74	282.45	287.32	286.49	10.29	0.07	0.10	0.10	0.001	0.72

[a]A total of 156 barrows with initial weight of 131.6 lb.

[b] Pre-feeding period was a minimum of an eight-week acclimation period.

[c]A total of 48 pigs were selected from the original 156 pigs for the metabolism portion of the trial.

[d]A total of 44 pigs were fed in the post-feeding period of the trial; four pigs were removed from treatment during the metabolism portion of the trial.

Table 6. Effects of Increasing Dietary Pantothenic Acid (PA) on Carcass Characteristics of Finishing Pigs Feed Ractopamine HCL (RAC), Exp. 2[a]

	RAC, ppm											
	0.0			10.0								
	Added Pantothenic Acid, ppm							Probability, P <				
Item	0.0	22.5	45.0	0.0	22.5	45.0	SE	PA	Linear	Quadratic	RAC	RAC X PA
Dressing percentage	70.94	70.30	71.21	71.40	71.40	72.19	0.76	0.38	0.37	0.27	0.09	0.84
Hot-carcass wt, lb	189.40	194.54	194.95	201.72	205.15	206.86	8.24	0.10	0.04	0.48	0.001	0.94
Cold-carcass wt, lb	184.41	188.95	189.54	196.41	199.24	201.43	8.50	0.12	0.05	0.61	0.001	0.93
Backfat measurement, in												
First rib[b]	1.21	1.28	1.26	1.19	1.44	1.28	0.09	0.24	0.47	0.13	0.53	0.61
Last rib[b]	0.84	0.88	0.85	0.83	0.80	0.86	0.05	0.91	0.70	0.87	0.51	0.69
Last lumbar[b]	0.80	0.82	0.78	0.77	0.83	0.89	0.06	0.58	0.33	0.72	0.55	0.26
Average backfat[b]	0.96	1.00	0.97	0.93	1.02	1.00	0.05	0.41	0.42	0.30	0.89	0.81
Tenth rib[b]	0.85	0.93	0.85	0.79	0.73	0.85	0.07	0.87	0.61	0.92	0.20	0.27
Percentage lean[b]	53.72	51.55	54.63	55.19	55.32	54.26	1.46	0.61	0.99	0.32	0.18	0.22
Longissimus muscle area, in[b]	7.36	6.68	7.83	7.92	7.66	7.74	0.45	0.22	0.69	0.09	0.19	0.34
Leaf fat, lb	3.26	3.37	2.76	2.43	2.51	2.66	0.32	0.14	0.67	0.55	0.04	0.40
Color [c]	2.38	2.26	2.11	1.94	2.40	2.05	0.24	0.48	0.71	0.25	0.47	0.71
Marbling [d]	1.44	1.21	1.21	1.25	1.21	1.29	0.13	0.60	0.48	0.48	0.72	0.48
Firmness[e]	1.88	1.90	1.61	1.69	1.90	1.51	0.33	0.12	0.17	0.11	0.46	0.17
Drip loss, %	6.39	6.87	8.06	9.74	7.26	9.61	1.17	0.32	0.49	0.17	0.06	0.41

[a]A total of 44 barrows with initial weight of 131.6 lb were fed pantothenic acid dietary treatments for eight weeks and fed RAC diets for 28 d.
[b]Covariate with hot-carcass weight.
[c]Scoring system of 1 to 5: 2=grayish pink; 3=reddish pink; 4=purplish red.
[d]Scoring system of 1 to 5: 2=traces to slight; 3=small to modest; 4=moderate to slightly abundant.
[e]Scoring system of 1 to 5: 2=soft and exudative; 3=slightly firm and moist; 4=firm and dry.

Table 7. Effects of Increasing Dietary Pantothenic Acid on Nitrogen Balance of Finishing Pigs Feed Ractopamine HCl (RAC)[a]

	RAC, ppm											
	0.0			10.0								
	Added Pantothenic Acid, ppm							Probability, P <				
Item	0.0	22.5	45.0	0.0	22.5	45.0	SE	PA	Linear	Quadratic	RAC	RAC X PA
DM digestibility, %	71.38	72.10	73.14	71.86	72.05	69.63	1.87	0.86	0.85	0.60	0.32	0.24
N digestibility, %	72.23	72.92	70.06	66.57	66.10	69.76	0.05	0.98	0.87	0.96	0.13	0.60
DE, kcal/g	3265	3398	3350	3351	3345	3200	83.60	0.35	0.63	0.17	0.48	0.22
ME, kcal/g	3129	3263	3225	3234	3227	3082	89.40	0.36	0.67	0.17	0.65	0.18
N intake, g/d	86.55	88.95	88.24	87.37	88.76	89.24	3.77	0.22	0.15	0.34	0.59	0.86
Fecal N, g/d	25.65	26.12	26.10	29.42	27.59	32.89	1.78	0.32	0.28	0.29	0.01	0.35
Urinary N, g/d	36.30	38.90	35.83	28.51	30.61	28.42	3.00	0.57	0.92	0.30	0.01	0.99
Total N, g/d	61.94	65.02	61.93	57.93	58.20	61.28	3.45	0.85	0.62	0.77	0.17	0.66
N retained, g/d	24.61	23.93	26.31	29.44	30.55	26.93	5.31	0.99	0.97	0.95	0.07	0.68
BV, %	39.29	38.07	41.91	50.16	48.68	46.88	0.06	0.94	0.94	0.75	0.01	0.75
N retained as % N intake	27.77	27.08	29.93	33.43	33.90	30.24	4.99	0.98	0.88	0.96	0.13	0.60

[a]A total of 44 barrows with initial weight of 131.6 lb were fed pantothenic acid dietary treatments for eight weeks and fed RAC diets for 28 d.

Swine Day 2004

INFLUENCE OF CHROMIUM SOURCE ON PLASMA NON-ESTERIFIED FATTY ACID CONCENTRATIONS IN GROWING-FINISHING PIGS[1]

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Summary

A total of 150 pigs (PIC, initial body weight 178.9 ± 14.7 lb) were used in a 35-d study to evaluate the effect of chromium propionate and chromium tripicolinate on plasma non-esterifed fatty acids (NEFA) in growing-finishing pigs. Our objective was to determine if differences between sources and rate of source being fed can be detected in fasted growing-finishing pigs by measuring plasma NEFA. Pigs were randomly allotted to one of the five dietary treatments arranged as a 2 × 2 factorial plus negative control (no chromium). Main effects were source of chromium (chromium propionate and chromium tripicolinate) and chromium concentration (100 or 200 ppb). On d 34, feeders were removed from pens 16 h before collecting blood on d 35 for analysis of plasma NEFA. There were no interactions (P>0.10) observed for chromium source, rate, or gender. There was no effect observed (P>0.10) of chromium source or rate on ADG, ADFI, or F/G. There was no chromium-source effect (P>0.73) observed for NEFA, but there was a tendency (quadratic, P>0.08) for plasma NEFA to decrease in pigs fed 100 ppb chromium tripicolinate and to increase in the pigs fed 200 ppb tripicolinate.

(Key Words: Chromium Propionate, Chromium Tripicolinate, NEFA, Pigs.)

Introduction

Chromium picolinate is currently used at 200 ppb in many sow diets to improve insulin sensitivity, glucose metabolism, and reproductive performance. Chromium propionate has recently been introduced to the market, and the U.S. Documentation for the approval of these sources was based on their ability to reduce non-esterified fatty acid (NEFA) concentrations in a fasted pig. It is generally accepted that the source of chromium affects bioavailability, with organic chromium potentially having a greater bioavailability than inorganic sources. Measuring NEFA concentration in fasted growing-finishing pigs may be the lowest-cost and quickest method to determine the relative response to various chromium sources being compared with each other to determine source bioavailability. In the experiment done by Kemin Industries for chromium propionate approval, NEFA concentration decreased quadratically, with the optimal inclusion rate of 200 ppb. Additional Cr sources have also been approved on the basis of demonstrating changes in NEFA concentration. Therefore, our objective was to determine if differences

[1]Appreciation is expressed to Kemin Industries for providing partial financial support and the chromium propionate used in this experiment.
[2]Food Animal Health and Management Center.
[3]Kemin Inc., Des Moines IA.

between Cr sources and rate fed can be detected in fasted growing-finishing pigs by measuring NEFA.

Procedures

A total of 150 pigs (PIC, Franklyn, KY), with initial body weight 178.9 ± 14.7 lb, were used in a 35-d study to evaluate the effect of chromium propionate and chromium tripicolinate on plasma NEFA in growing-finishing pigs. Pigs were blocked by weight and gender and were randomly allotted to one of five dietary treatments. There were 40 pens of gilts and 35 pens of barrows, with two pigs per pen and 15 pens per treatment. Pigs had ad libitum access to feed and water. Pigs were housed on totally slatted concrete floors in 4 × 4 ft pens. The dietary treatments were arranged as a 2 × 2 factorial plus a negative control (no chromium); main effects were chromium source (chromium propionate or chromium tripicolinate) and concentration (100 or 200 ppb, Table 1). Pigs were weighed and feed intake was determined on d 0, 17 and 35. These data were used to calculate ADG, ADFI, and feed efficiency (F/G). On d 34, feeders were removed from pens 16 h before collection of plasma on d 35. After plasma samples were obtained from all pigs, pigs were weighed to determine final weight. Plasma was analyzed for NEFA concentration by using a NEFA C test kit (Wako Diagnostics, VA). Statistical analysis was performed by using the MIXED procedure in SAS v. 8.1.

Results and Discussion

There were no interactions (P>0.10) observed for chromium source or rate or gender. There was no effect (P>0.10) of chromium source or rate on ADG, ADFI, or F/G (Table 2). There also was no chromium-source effect (P>0.73) observed for NEFA. There was a tendency (quadratic, P>0.08) for NEFA to decrease, then increase, in pigs fed chromium tripicolinate.

Previous research conducted at Louisiana State University used NEFA to evaluate chromium sources. Similar to our study, that study found no differences in growth performance, but plasma NEFA concentrations were decreased (P>0.02) in pigs fed the diets containing chromium tripicolinate; no effect (P>0.12) on plasma NEFA was observed in pigs fed chromium propionate, compared with that of control pigs. But follow-up study also demonstrated a linear (P > 0.09) decrease in plasma NEFA concentration for early finishing pigs fed increasing rates of supplemental chromium propionate.

Table 1. Ingredient and Chemical Composition of Diets (As-fed Basis)[a]

Ingredient	Percentage
Corn	80.10
Soybean meal (46.5% CP)	17.35
Monocalcium phosphate (21% P)	0.80
Limestone	0.90
Salt	0.35
Vitamin premix	0.15
Trace mineral premix	0.15
Sand[b]	0.05
L-Lysine HCl	0.15
Total	100.00

[a]Dietary treatments were formulated to contain 0.85% lysine, 0.57% Ca, and 0.51% P.
[b]Sand was replaced with chromium propionate or chromium tripicolinate at .5 or 1 lb/ton to provide 100 or 200 ppb for each chromium source.

Plasma NEFA concentrations are expected to decrease with the addition of chromium to the diets, but this has not been demonstrated in every experiment. In addition, researchers from Louisiana State University also reported no change in plasma NEFA with chromium tripicolinate, chromium chloride, or chromium nicotinate.

The decrease in plasma NEFA concentration indicated in previous research is an indication that chromium may have an influence on lipid metabolism in swine and, therefore, may be the most cost-effective method of measuring the effects of supplemental chromium. In our study, however, the tendency toward a quadratic response in plasma NEFA concentration indicated that NEFA concentrations were not consistently reduced by added chromium from either source. Therefore, further research investigating the effects of chromium use in finishing pigs needs to be conducted.

Table 2. Effects of Chromium Source on Growth Performance and Non-esterified Fatty Acid (NEFA) Plasma Concentration[a]

							Probabilities, P<					
		Chromium Tripicolinate		Chromium Propionate					Chromium Tripicolinate		Chromium Propionate	
Item	Control	100 ppb	200 ppb	100 ppb	200 ppb	SE	Cr	Source	Linear	Quadratic	Linear	Quadratic
Day 0 to 36												
Initial wt, lb	179.22	178.99	179.50	178.96	179.09	3.80	0.49	0.37	0.40	0.19	0.71	0.51
ADG, lb	1.89	1.84	1.82	1.89	1.86	0.06	0.85	0.41	0.36	0.78	0.67	0.81
ADFI, lb	6.27	6.00	6.15	6.20	6.23	0.18	0.69	0.34	0.55	0.22	0.86	0.78
F/G	3.33	3.27	3.38	3.32	3.36	0.08	0.80	0.90	0.60	0.28	0.82	0.75
Final Wt, lb	245.22	243.26	243.26	245.01	244.10	4.65	0.89	0.48	0.43	0.64	0.66	0.88
NEFA, mmol/L	0.44	0.39	0.54	0.42	0.47	0.05	0.21	0.73	0.14	0.08	0.61	0.54

[a]A total of 150 pigs (PIC, initial BW = 178.9 ± 14.7 lb) were used in the experiment. The values represent two pigs per pen and 15 pens per treatment.

Swine Day 2004

EFFECT OF DIETARY L-CARNITINE AND RACTOPAMINE-HCL (PAYLEAN) ON THE METABOLIC RESPONSE TO HANDLING IN GROWING-FINISHING PIGS

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Summary

Two experiments (384 pigs) were conducted to determine the interactive effect of dietary L-carnitine and ractopamine·HCl (Paylean) on the metabolic response to handling. Experiments were arranged as split plots, with handling as the main plot and diet as subplots (4 pens/treatment). Dietary L-carnitine (0 or 50 ppm) was fed from 85 lb to the end of the trials (260 lb) and Paylean (0 or 20 ppm) was fed for the last 4 wk of each trial. At the end of each trial, two pigs per pen were assigned to one of two handling treatments. Gentle-handled pigs were moved at a moderate pace three times through a 164-ft course and up and down a 15° loading ramp. Non-gentle-handled pigs were moved at a faster pace, up and down a 30° ramp, and were shocked by an electrical prod. Blood was collected immediately before and after handling in Exp. 1 and immediately after and 1 h after handling in Exp. 2. Feeding Paylean increased (P<0.01) ADG and F/G, but there was no (P>0.10) effect of L-carnitine on growth performance in either trial. In Exp. 1 and 2, non-gentle handling increased (P<0.01) lactate dehydrogenase (LDH), lactate, cortisol, and rectal temperature, and decreased pH. In Exp. 1, a Paylean × handling interaction was observed for pH (P<0.01), temperature (P<0.06), and cortisol (P<0.064). Feeding Paylean decreased pH, increased cortisol, increased temperature, and tended (P<0.09) to increase blood lactate when pigs were non-gentle handled, but not when they were gentle handled. Pigs fed Paylean had increased (P<0.01) LDH compared with that of pigs not fed Paylean. Pigs fed L-carnitine had increased (P<0.03) lactate compared with that of pigs not fed L-carnitine. In Exp. 2, pigs fed Paylean had lower (P<0.02) pH immediately after handling, but pH returned to control levels (P>0.96) by 1 h post-handling. Lactate, LDH, cortisol, and temperature changes from immediately post-handling to 1 h post-handling were not different for pigs fed L-carnitine or Paylean, suggesting that L-carnitine did not decrease recovery time of pigs subjected to non-gentle handling. These results demonstrate the importance of proper handling technique to minimize stressful events during the loading and transporting of pigs, regardless of whether either of these feed additives is being fed. This was evident by the large magnitude of the metabolic changes observed for the handling treatments, whereas in general the magnitude of metabolic changes from the dietary treatments was much smaller. Nonetheless, pigs fed Paylean are more susceptible to stress when handled aggressively, compared with pigs not fed Paylean. Dietary L-carnitine did not alleviate the effects of stress when fed in combination with Paylean.

(Key Words: L-carnitine, Pigs, Ractopamine HCL.)

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Introduction

The increased incidence of downer pigs and metabolic acidosis has been well recognized as a swine industry problem and has resulted in substantial economic losses. A downer pig has been categorized as a pig that becomes fatigued, refuses to get up and walk, or can not keep up with its contemporaries while loading, unloading, or moving through the packing plant. The prevalence of downer pigs has been attributed to several factors, including animal handling, genetics, and muscling. The occurrence of downer pigs may be amplified by the industry trend of producing a more heavily muscled, lean genotype pig.

Non-gentle handling of pigs results in increased concentrations of serum lactate, decreased pH, and increased incidence of downer pigs. Previous research at Kansas State University has suggested that supplemental L-carnitine may improve pork quality in pigs fed Paylean. The improvements in meat quality of pigs fed L-carnitine in combination with Paylean may be the result of L-carnitine's affect on the pigs' metabolic parameters, either antimortem or postmortem.

Because of the known influence of L-carnitine on enzymes involved in lactic acid production, L-carnitine may be able to reduce the number of downer pigs of pigs fed Paylean in commercial production facilities by altering the metabolic response to handling. Our objective was to evaluate the interaction between feeding Paylean and carnitine in gentle- and non-gentle-handled, market-weight finishing pigs.

Procedures

General

Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee (Protocol No. 2156) and were conducted at the Kansas State University Swine Teaching and Research Center. Pigs were housed in a modified open-front building with 50% solid concrete and 50% concrete slat flooring. Each 6 × 16-ft pen had a two-hole dry self-feeder and a nipple waterer to allow ad libitum access to feed and water.

A total of 384 pigs (PIC L 42 dams × L327 sire) were used in two experiments. All pigs were used for the growth performance criteria, and a sub-sample of 128 pigs were used for the handling and stress data. In each experiment, 192 pigs were blocked by weight and ancestry (initially 85 lb) in a split-plot design with two handling treatments (whole plot) and four dietary treatments (subplots). There were 12 pigs per pen and 16 pens (four replications) per experiment. The four dietary treatments were arranged as a 2 × 2 factorial. Pigs were fed a corn-soybean meal diet (Table 1) with added L-carnitine (0 or 50 ppm) from 85 lb until the end of each experiment (260 lb). The basal diet was formulated to contain 1.20% total lysine from 85 to 120 lb (phase 1), and 1.00% total lysine from 120 to 190 lb and 190 to 260 lb (phases 2 and 3, respectively). Dietary Paylean treatments (0 or 20 ppm) were fed for the last four weeks of each experiment (approximately 190 to 260 lb). For the remaining nutrients, all diets were formulated to meet or exceed NRC nutrient requirement estimates.

Growth Performance

Weights were obtained on all pigs, and feed added and feeder weights were recorded, every 14 d during the experiment until the last four wk, at which time measurements were recorded at the beginning (190 lb) and the end (260 lb) of the 4-wk period to calculate ADG, ADFI, and F/G. Pigs were only weighed at the beginning and the end of the last 4-wk period (Paylean supplementation) so that they did not become accustomed to the routine of being handled.

Stress Model

The two handling treatments (gentle and non-gentle) were imposed at the end of the experiment (260 lb). Two pigs from each pen in a block were subjected to the gentle handling treatment and two pigs from each pen were subjected to the non-gentle handling treatment so that one pig per pen in a block (one pig from each dietary treatment) would be subjected to the respective handling treatment at the same time (groups of four pigs). Pigs were selected randomly from each pen. The two handling treatments were conducted in random order to avoid circadian and ambient-temperature bias. The handling portion of the study was conducted in a different location than where the pigs were housed for the growth portion of the trial. This was done so that administration of the handling treatments did not bias subsequent groups.

In the gentle handling treatment, the handler moved pigs three times through a 164-ft course , including up and down a 15^{o} loading ramp, using a sorting board at a moderate pace (Figure 1). At the top of the loading ramp, pigs were moved onto a hydraulic pig cart, turned around, and moved back down the loading ramp. The 164-ft course consisted of moving pigs back and forth (3 laps, for a total of 492 ft) to simulate movement in the alleyway of the finishing barn. In the non-gentle handling treatment, pigs were moved at a quicker pace through the course, including up and down a 30 ^{o} loading ramp. Panels divided the alleyway and narrowed, resulting in crowding, at one end to simulate a single chute to model commercial loading and slaughter facilities. Pigs were subjected to three (one-second) stimulations by an electrical prod (The Green One HS200, Hot-Shot, Savage, MN) per time around the course. The objective was to model the mild and moderate stress that pigs incur as they are loaded and transported to and in slaughter facilities.

Rectal temperature was recorded and blood was collected immediately before and after handling in Exp. 1 and immediately after and 1 h after handling in Exp. 2. The blood was collected via the anterior vena cava by a veterinarian so that samples could be obtained quickly to prevent additional stress. Pigs were restrained for blood collection with a snout snare and were quickly released after blood collection. Pigs were restrained for less than approximately 30 s. Blood samples were immediately placed on ice and transported to the Kansas State University College of Veterinary Medicine to be analyzed for serum LDH, lactate, pH, glucose, urea nitrogen, and cortisol by using an autoanalyzer. The time elapsed from blood collection to arrival at the laboratory was approximately 15 min. In Exp. 1, heart rate was measured during the handling treatments by fitting the pigs with a Polar Vantage NV heart-rate monitor (Polar Electro Oy, Kempele, Finland) to record and store successive interbeat intervals.

Statistical Analyses

Data were analyzed as a split-plot design, with handling (gentle or non-gentle) as the whole plot and diet (L-carnitine, 0 or 50 ppm; and Paylean, 0 or 20 ppm) as the subplot. In each experiment, there were four observations per treatment diet (pens) for growth performance. A sub-sampling of individual pigs (four pigs per pen; two for gentle and two for non-gentle handling) were used for metabolic and physiological response data. Analysis of variance was performed by using the PROC MIXED procedure of SAS.

Results

Combined Growth Performance

The growth performance data from Exp. 1 and 2. were combined (Table 2). There was no effect (P>0.40) of feeding pigs L-carnitine on ADG, ADFI, or F/G from 85 to 190 lb (pre-Paylean). These results are similar to previous studies conducted at Kansas State University in which dietary L-carnitine was supplemented during the entire finishing period. From d 0 to 28 of the Paylean supplementa-

tion period, there were no Paylean × L-carnitine interactions (P>0.28) or main effects of L-carnitine (P>0.58) for any of the growth performance criteria. Pigs fed Paylean had improved (P<0.01) ADG and F/G.

For the overall finishing period (85 to 260 lb), there were no Paylean × L-carnitine interactions (P>0.53) observed for ADG, ADFI, or F/G or for main effects of L-carnitine. Pigs fed Paylean had greater (P<0.01) ADG and F/G than did pigs not fed Paylean.

Handling

Experiment 1. There were no pre-handling Paylean × L-carnitine interactions (P>0.20) on any of the pre-handling metabolite measurements (Table 3). There were no Paylean × L-carnitine × handling interactions (P>0.14) or Paylean × L-carnitine interactions (P>0.15) immediately post-handling or for the difference between pre-handling and post-handling for any of the criteria measured.

Pigs that were subjected to the non-gentle handling treatment or fed Paylean had increased (P<0.01) LDH concentration post-handling and had a greater (P<0.01) difference (LDH increase) between pre-handling and post-handling than did pigs that were handled gently or were not fed Paylean.

Pigs fed Paylean had an increased (P<0.01) pre-handling lactate concentration, compared with that of pigs not fed Paylean. A post-handling Paylean × handling interaction trend (P<0.13) was observed for lactate concentration. Pigs that were non-gentle handled or pigs that were fed Paylean had a higher lactate concentration than did pigs that were gentle handled or were not fed Paylean. Lactate concentration was highest post-handling for pigs that were non-gentle handled and fed Paylean. This resulted in a Paylean × handling interaction (P<0.09) for the difference between pre-handling and post-handling lactate concentration. Although pigs fed Paylean had higher (P<0.01) pre-handling lactate concentration than did pigs not fed Paylean, it increased even more post-handling for pigs that were non-gentle handled.

Pigs fed Paylean had a lower (P<0.04) pre-handling pH compared with pigs not fed Paylean. A Paylean × handling interaction (P<0.01) was observed for pH post-handling. Pigs that were subjected to the non-gentle handling treatment had lower post-handling pH than did pigs that were gentle handled, and it was even lower for pigs that were fed Paylean and non-gentle handled. This resulted in a Paylean × handling interaction (P<0.05) for the difference in pH between pre-handling and post-handling. The pH of pigs fed Paylean was initially lower than that of pigs not fed Paylean and pH decreased more for pigs that were non-gentle handled and were fed Paylean.

A trend for an L-carnitine × handling interaction (P<0.09) was observed for glucose concentration post-handling and for the difference between pre-handling and post-handling glucose concentration. Pigs that were non-gentle handled had a higher (P<0.01) post-handling glucose concentration and a greater (P<0.01) difference (increase in glucose) between pre-handling and post-handling. Pigs that were fed L-carnitine also had a slightly higher (P<0.06) post-handling glucose concentration.

There was no effect of dietary treatment (P>0.28) on pre-handling or post-handling urea nitrogen concentration. But pigs that were non-gentle handled had a greater difference (greater increase) in urea nitrogen concentration between pre-handling and post-handling.

A post-handling Paylean × handling interaction (P<0.04) was observed for post-handling cortisol concentration. Pigs that were non-gentle handled had increased post-handling cortisol concentration, compared with pigs that were gentle handled. Pigs that

were fed Paylean and non-gentle handled had the highest post-handling cortisol concentration, compared with that of pigs fed the other treatment diets.

A Paylean × handling interaction ($P<0.06$) trend was observed for the difference in rectal temperature between pre-handling and post-handling. Pigs that that were handled non-gentle had higher post-handling rectal temperature, and the difference between pre-handling and post-handling was greater for pigs that were handled non-gentle than for pigs that were gentle handled. There was a trend ($P<0.06$) for pigs fed Paylean to have a higher post-handling rectal temperature than did pigs that were not fed Paylean. Pigs that were non-gentle handled and fed Paylean had the highest increase in rectal temperature, compared with pigs fed the other treatment diets.

Pigs fed Paylean tended ($P<0.11$) to have faster minimum and average heart rates during the handling treatment than did pigs not fed Paylean (Table 5). Pigs that were non-gentle handled had increased ($P<0.01$) average, maximum, and change in heart rate, compared with pigs that were handled gently.

Experiment 2. A trend ($P < 0.08$) for an L-carnitine × handling interaction was observed for post-handling LDH concentration (Table 5). Pigs fed L-carnitine and handled gentle had a lower LDH concentration than did pigs not fed L-carnitine and handled gentle; but pigs fed L-carnitine and handled non-gentle had a higher LDH concentration than did pigs not fed L-carnitine and handled non-gentle. Pigs fed Paylean had higher ($P<0.01$) post-handling and 1-hr post-handling LDH concentrations than did pigs not fed Paylean. Pigs that were non-gentle handled had a higher ($P<0.01$) post-handling LDH concentration, and the difference between immediately post-handling and 1 hr post-handling was greater ($P<0.01$), for pigs that were non-gentle handled than for pigs that were handled gently.

Pigs that were handled non-gentle or fed Paylean had a higher ($P<0.05$) post-handling lactate concentration than did pigs handled gently or not fed Paylean. There was a trend for a Paylean × handling and a L-carnitine × handling interaction for 1-hr post-handling lactate concentration. Pigs that were handled non-gently had a higher lactate concentration 1 hr post-handling than did pigs handled gently, and it was higher for pigs fed Paylean or L-carnitine than for pigs not fed Paylean or L-carnitine. The difference between post-handling and 1-hr post-handling lactate concentration was greater ($P<0.01$) for pigs that were handled non-gentle than for pigs handled gently. The difference (greater decrease) was greater because post-handling lactate concentration was much higher for pigs that were handled non-gentle than for pigs handled gently, and had further to decrease to approach normal levels as the pig recovered from the non-gentle handling.

Post-handling pH was lower ($P<0.02$) for pigs that were handled non-gentle or fed Paylean than for pigs that were handled gentle or not fed Paylean. The pH of pigs that were handled non-gentle was still lower ($P<0.03$) 1 hr post-handling than for pigs that were handled gentle. A trend was observed for a Paylean × handling interaction ($P<0.08$) for the difference between pH measured post-handling and 1 hr post-handling. Pigs that were non-gentle handled or fed Paylean had a lower post-handling pH; therefore, the difference between post-handling and 1 hr post-handling was greater for pigs that were non-gentle handled or fed Paylean.

Pigs that were handled non-gentle had a higher ($P<0.01$) post-handling glucose concentration than did pigs that were handled gentle. Pigs that were fed Paylean tended to have a lower ($P<0.07$) glucose concentration post-handling than did pigs that were not fed

Paylean. A trend was observed for a Paylean × L-carnitine interaction for glucose concentration 1 hr post-handling. Pigs that were fed Paylean had a lower glucose concentration 1 hr post-handling than did pigs that were not fed Paylean, and pigs that were fed L-carnitine had a lower glucose concentration 1 hr post-handling than did pigs that were not fed L-carnitine. Glucose concentration was lowest 1 hr post-handling for pigs that were fed Paylean and L-carnitine, with that of pigs fed the other treatment diets. A trend was observed for an L-carnitine × handling interaction ($P < 0.09$) for glucose concentration 1 hr post-handling. Pigs that were non-gentle handled had a lower glucose concentration 1 hr post-handling than did pigs that were gentle handled. Pigs fed L-carnitine and handled gently had an increased glucose concentration, compared with that of pigs that were not fed L-carnitine and handled gently; but pigs fed L-carnitine and handled non-gently had a decreased glucose concentration, compared with that of pigs that were not fed L-carnitine and handled non-gentle. The difference between post-handling and 1-hr post-handling glucose concentration was ($P<0.01$) greater (greater decrease) for pigs that were non-gentle handled than for pigs that were handled gently.

A Paylean × L-carnitine × handling interaction ($P<0.04$) was observed for post-handling and 1-hr post-handling urea nitrogen concentration. Pigs that were non-gentle handled had higher post-handling and 1-hr post-handling urea nitrogen concentrations than did pigs that were handled gently. Pigs that were fed Paylean or L-carnitine had a lower urea nitrogen concentration post-handling and 1 hr post-handling than did pigs that were not fed Paylean or L-carnitine. The difference between post-handling and 1-hr post-handling urea nitrogen concentrations was less ($P<0.01$) for pigs that were handled non-gentle than for pigs that were handled gently.

A Paylean × L-carnitine × handling interaction trend ($P<0.07$) was observed for post-handling cortisol concentration. Pigs that were non-gentle handled had a higher post-handling cortisol concentration than did pigs handled gently. Pigs fed Paylean or L-carnitine had an increased cortisol concentration, compared with that of pigs not fed Paylean or L-carnitine, and the post-handling cortisol concentration was highest for pigs fed Paylean and L-carnitine and handled non-gentle, compared with that of pigs fed the other treatment diets. Pigs that were handled non-gentle had ($P<0.01$) higher 1-hr post-handling cortisol concentration and a greater ($P<0.01$) difference (increase) in cortisol concentration between post-handling and 1 hr post-handling, than did pigs that were handled gentle.

Pigs fed L-carnitine had a lower ($P<0.01$) pre-handling rectal temperature than did pigs not fed L-carnitine. A Paylean × L-carnitine interaction ($P<0.02$) was observed for post-handling rectal temperature, and a Paylean × L-carnitine trend ($P<0.06$) was observed for 1-hr post-handling rectal temperature. Pigs fed Paylean had a higher rectal temperature than did pigs not fed Paylean, but it was highest for pigs fed Paylean and L-carnitine, compared with that of pigs fed Paylean and not fed L-carnitine. Pigs that were non-gentle handled had a higher ($P<0.01$) rectal temperature post-handling and 1 hr post-handling than did pigs handled gently.

Discussion

Growth-performance benefits for pigs fed diets containing Paylean were similar to previous experiments conducted at Kansas State University, but a lack of L-carnitine response in the late-finishing period is somewhat different than previous experiments found. Some of the differences may be a result of location of the experiments. Two of the previous experiments that report benefits were conducted in a commercial finishing facility.

Lactate dehydrogenase is a cytoplasmic enzyme that catalyzes a reversible reaction

that converts pyruvate to lactate at the end of anaerobic glycolysis. There are several isoenzymes of LDH. Isoenzyme analysis requires special assays that are not widely available, so in our experiments we analyzed total LDH. An increase in LDH is an indicator of muscle damage and hemolysis. Increased LDH activity may be due to local or diffuse cell damage. Pigs that were non-gentle handled had greater LDH immediately post-handling than did pigs that were handled gently. Although LDH concentrations increased between pre-handling and post-handling for pigs handled gently, the magnitude was minor compared with that of the pigs that were non-gentle handled. This is just one of the criteria involved that demonstrates that the handling course was successful in eliciting differences between pigs that were handled gentle and pigs that were handled non-gentle. Pigs that were fed Paylean were more susceptible to an increase in LDH due to either handling treatment and had greater LDH 1 hr after handling, which indicates that it takes longer for LDH to return to normal levels in pigs fed Paylean than in pigs not fed Paylean. Research at Kansas State University has shown that dietary L-carnitine increased pyruvate carboxylase and decreased LDH in pigs. An increase in pyruvate carboxylase may direct pyruvate away from lactate, thus reducing substrate for lactic acid synthesis. Furthermore, a decrease in LDH may delay the onset of glycolysis. In this experiment, however, added L-carnitine did not alleviate the production of LDH in pigs that were non-gentle handled or fed Paylean.

Serum lactate levels have previously been shown to increase in aggressively handled pigs compared with those being handled gently. Our observations are in agreement with these reports. Within 1 hr post-handling, lactate concentrations were still elevated in pigs handled non-gentle, compared with that in pigs that were handled gentle. This illustrates the importance in allowing ample time for recovery of pigs after delivery to slaughter facilities so that the increased concentration of lactate does not adversely affect meat quality. It is of interest that pigs fed Paylean had increased levels of pre-handling lactate, compared with that of pigs not fed Paylean. This may suggest that pigs fed Paylean were in a partial acidotic state before being handled. Also, pigs that were fed Paylean had greater post-handling lactate concentrations than did pigs not fed Paylean. Pigs that were fed Paylean and non-gentle handled had the greatest lactate concentrations, and it remained greater 1 hr post-handling. Because we did not observe differences in LDH for pigs fed added L-carnitine, it is not surprising that lactate concentrations were not affected by L-carnitine.

Downer pigs have been reported to have decreased blood pH. Pre-handling pH was less in pigs fed Paylean than in pigs not fed Paylean. This supports the observation that pre-handling lactate concentrations were increased for pigs fed Paylean, and may simply be a description of lactate level and acid-base balance. Non-gentle handling of pigs in our experiment decreased post-handling pH, compared with that of pigs handled gently, and it was lowest for pigs fed Paylean, suggesting that Paylean amplifies the effect of non-gentle handling and that pigs were in a state of metabolic acidosis. Pigs fed Paylean did not have a different pH 1 hr post-handling than did pigs not fed Paylean. Although pH was still decreased 1 hr post-handling for pigs handled non-gently, it was near levels of pigs that were handled gently, in comparison to lactate levels, which were still almost 5-fold higher at 1 hr post-handling for pigs handled non-gentle. Although we did observe a trend for a Paylean × L-carnitine interaction for the change in pH between post-handling and 1 hr post-handling, pigs fed L-carnitine in combination with Paylean tended to have an increased pH (better recovery) within 1 hr post-handling, compared with that of pigs not fed L-carnitine.

We observed increased glucose concentrations post-handling in pigs that were handled

non-gentle. In Exp. 2, pigs fed Paylean tended to have a decreased post-handling glucose concentration. Pigs fed Paylean or L-carnitine had decreased 1-hr post-handling glucose concentration, and it was lowest for pigs fed both Paylean and L-carnitine.

In our first experiment, pigs that were non-gentle handled had a greater change (increase) in urea nitrogen concentration between pre-handling and post-handling concentrations. In Exp. 2, pigs that were non-gentle handled had increased urea nitrogen concentrations. This may be the result of increased muscle breakdown occurring from the stress of non-gentle handling. But pigs fed either Paylean or L-carnitine and non-gentle handled had decreased post-handling and 1-hr post-handling urea nitrogen concentrations.

Hypercortisolemia is a result of stress caused by an illness, trauma, or environmental changes that stimulate cortisol releasing hormone, then adrenocorticotrophic hormone (corticotropin), and thus stimulate the adrenal glands to produce more cortisol. Short stressful events (i.e., direct handling, isolation, and transportation) are usually followed by an increase in stress hormones. Research has previously shown that downer pigs have increased cortisol levels, compared with those of non-downer pigs. Pigs that were non-gentle handled in our study had increased levels of cortisol and it was increased further for pigs that were fed Paylean (Exp. 1). Cortisol activity increases blood glucose concentrations by stimulating gluconeogenesis and creating a state of insulin resistance. This may partly explain the increase in glucose concentrations that we observed in pigs that were handled non-gentle.

Rectal temperatures and heart rate have been shown to increase after pigs are subjected to aggressive handling and use of electric prodding. Pigs that were non-gentle handled had an increased rectal temperature immediate post-handling (Exp. 1 and 2) and 1 hr post-handling (Exp. 2), compared with those of pigs that were handled gentle. Pigs that were fed Paylean also had increased post-handling and 1-hr post-handling rectal temperatures (Exp. 2) compared with those of pigs not fed Paylean, and temperatures were highest for pigs fed Paylean in combination with L-carnitine. In our experiment, pre-handling rectal temperature was lower for pigs fed L-carnitine; it is difficult, however, to explain a mechanism for this observation. Paylean tended to increase minimum and average heart rate in our experiment. Non-gentle handling greatly increased average heart rate. These results also indicate that our model was effective in simulating stress-response differences between the two handling treatments and Paylean treatment.

These results demonstrate the importance of proper handling technique to minimize stressful events during the loading and transporting of pigs, regardless of whether either of these feed additives is being fed. This was evident by the large magnitude of the metabolic changes observed for the handling treatments, whereas in general the magnitude of metabolic changes from the dietary treatments was much smaller. Nonetheless, pigs fed diets containing Paylean were more susceptible to adverse effects on metabolic parameters when handled aggressively than were pigs fed diets without Paylean. Finally, dietary L-carnitine did not alleviate the adverse effects, when fed in combination with Paylean.

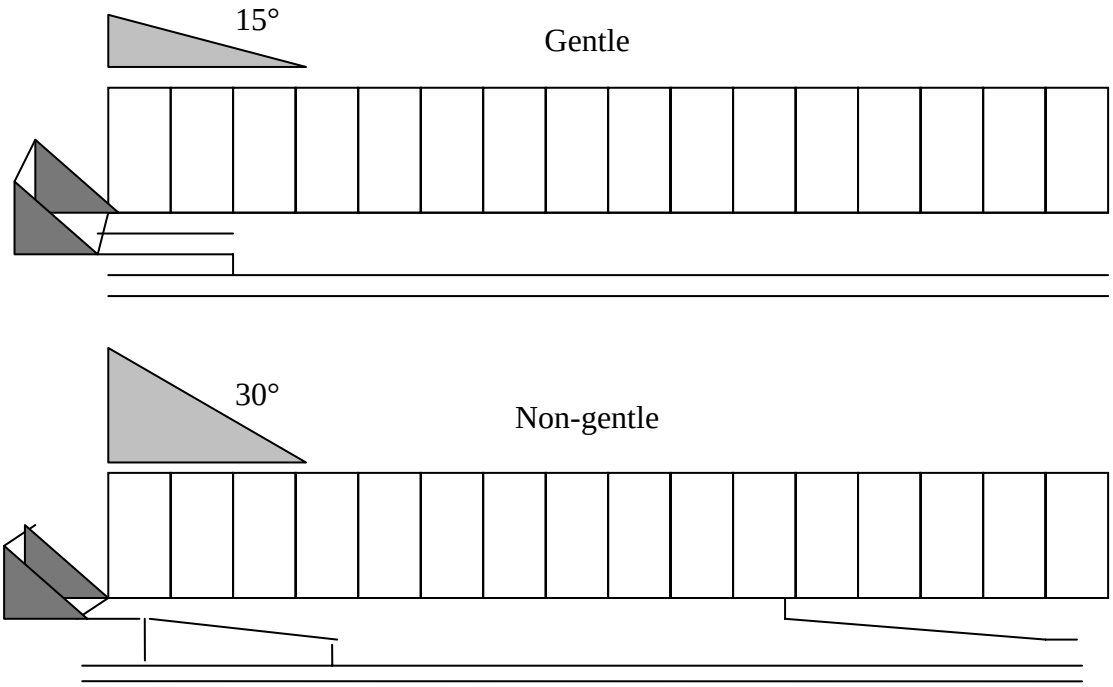

Figure 1. Handling-Course Diagram. Each handling treatment consisted of moving pigs back and forth (3 laps) in the alleyway of the finishing barn. In the gentle handling treatment, the handler moved pigs through the 164-ft course, including a 15° split-race loading ramp, by using a sorting board at a moderate pace. In the non-gentle handling treatment, pigs were moved at a quicker pace through the 164-ft course, including a 30° single-chute loading ramp, and panels were used to narrow the alleyway to stimulate crowding. Pigs were subjected to three (one-second) stimulations by an electrical prod per lap around the course.

Table 1. Basal Diet Composition (Exp. 1 and 2, As-fed Basis)[a]

Ingredient, %	Phase 1 [b]	Phase 2 [b]	Phase 3 [b]
Corn	66.92	74.26	74.45
Soybean meal (46.5% CP)	30.07	22.82	22.80
Monocalcium phosphate, 21% P	1.15	1.10	0.90
Limestone	0.96	0.93	0.90
Salt	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15
Medication[c]	0.05	0.05	-
Corn starch[d]	0.05	0.05	0.15
L-Lysine·HCl	0.15	0.15	0.15
Calculated Analysis			
CP (N × 6.25), %	19.67	16.92	16.92
Lysine, %	1.20	1.00	1.00
Lysine:calorie ratio, g/mcal	3.18	2.65	2.20
ME, kcal/lb	1,505	1,508	1,511
Ca, %	0.70	0.65	0.61
P, %	0.64	0.60	0.55

[a]Diets were formulated to meet or exceed NRC (1998) requirements.
[b]Phase 1 (85 to 120 lb); phase 2 (120 to 190 lb); phase 3 (190 to 260 lb).
[c]Provided 44 mg tylosin per kg diet.
[d]L-carnitine replaced cornstarch to provide either 0 or 50 ppm carnitine in phases 1, 2, and 3. Paylean replaced cornstarch to provide either 0 or 20 ppm ractopamine HCl in phase 3.

Table 2. Combined Interactive Effects between L-carnitine and Paylean on Growth Performance of Finishing Pigs in Exp. 1 and 2[a]

	L-carnitine, ppm							
	0		50					
	Paylean, ppm					Probability ($P <$)		
Item	0	20	0	20	SED	L-carnitine × Paylean	L-carnitine	Paylean
Pre-Paylean								
ADG, lb	2.12	-	2.07	-	0.04	-	0.40	-
ADFI, lb	5.47	-	5.47	-	0.07	-	0.95	-
F/G	2.56	-	2.63	-	0.02	-	0.45	-
Day 0 to 28								
ADG, lb	1.94	2.20	1.92	2.31	0.07	0.28	0.58	0.01
ADFI, lb	5.40	5.25	5.69	5.09	0.35	0.53	0.86	0.31
F/G	2.70	2.33	2.94	2.17	0.07	0.30	0.94	0.01
Overall								
ADG, lb	2.05	2.14	2.05	2.14	0.02	0.83	0.76	0.01
ADFI, lb	5.40	5.31	5.47	5.29	0.13	0.72	0.88	0.36
F/G	2.63	2.50	2.70	2.44	0.02	0.53	0.68	0.01

[a]Values are means of eight observations (pens) and 12 pigs per pen.

Table 3. Interactive Effects of L-carnitine, Paylean, and Handling on Stress Criteria of Finishing Pigs (Exp. 1)[a]

	Gentle Handling				Non-gentle Handling											
	L-carnitine, ppm															
	0		50		0		50									
	Paylean, ppm									Probability ($P <$)						
Item	0	20	0	20	0	20	0	20	SED	L-carnitine × Paylean × Handling	L-carnitine × Paylean	L-carnitine × handling	Paylean× Handling	L-carnitine	Paylean	Handling
LDH, U/L																
Pre-handling	532.50	532.50	537.25	534.40	550.00	604.38	558.00	593.75	25.67	-	0.76	-	-	0.95	0.46	-
Post-handling	487.88	587.50	574.00	600.00	651.13	775.25	647.88	768.75	37.95	0.58	0.55	0.39	0.35	0.48	0.01	0.01
Difference	-44.62	55.00	36.75	65.60	101.13	170.87	89.88	175.00	28.43	0.51	0.69	0.34	0.89	0.41	0.01	0.01
Lactate, mmol/L																
Pre-handling	2.39	3.61	2.23	2.31	2.10	2.85	2.03	2.91	0.26	-	0.35	-	-	0.17	0.01	-
Post-handling	4.70	5.93	5.08	5.85	19.38	21.39	19.16	27.51	1.67	0.21	0.28	0.30	0.13	0.26	0.03	0.01
Difference	2.31	2.32	2.85	3.54	17.28	18.54	17.13	24.60	1.63	0.35	0.99	0.11	0.09	0.03	0.29	0.01
pH																
Pre-handling	7.39	7.37	7.40	7.40	7.41	7.43	7.40	7.39	0.01	-	0.81	-	-	0.20	0.04	-
Post-handling	7.41	7.39	7.41	7.38	7.20	7.11	7.22	7.05	0.02	0.32	0.29	0.71	0.01	0.60	0.01	0.01
Difference	0.02	0.02	0.01	-0.02	-0.21	-0.32	-0.18	-0.34	0.03	0.61	0.37	0.99	0.05	0.33	0.01	0.01
Glucose, mg/dL																
Pre-handling	87.25	88.38	88.50	89.75	87.88	84.25	82.50	88.25	1.82	-	0.20	-	-	0.86	0.54	-
Post-handling	92.00	84.50	90.00	88.13	128.25	122.13	138.13	149.00	5.02	0.57	0.27	0.09	0.49	0.06	0.82	0.01
Difference	4.75	-3.88	1.50	-1.62	40.37	37.88	55.63	60.75	5.37	0.92	0.54	0.08	0.51	0.09	0.67	0.01
Urea nitrogen, mg/dL																
Pre-handling	15.75	13.63	15.13	15.63	15.00	12.38	13.38	12.75	1.13	-	0.31	-	-	0.98	0.29	
Post-handling	15.88	13.63	15.50	15.88	16.38	13.88	14.88	14.13	1.17	0.85	0.36	0.51	0.77	0.89	0.28	0.73
Difference	0.13	0	0.37	0.25	1.38	1.50	1.50	1.38	0.20	0.34	0.75	0.75	1.00	0.11	0.52	0.01
Cortisol, ng/ml																
Pre-handling	12.45	14.81	14.15	9.92	15.99	18.36	12.93	15.11	1.73	-	0.33	-	-	0.18	0.70	-
Post-handling	42.85	46.21	36.20	34.03	49.48	60.86	48.15	61.68	5.07	0.49	0.76	0.10	0.04	0.08	0.02	0.01
Difference	30.40	31.39	22.05	21.98	33.49	42.49	35.22	46.57	4.10	0.83	089	0.13	0.21	0.09	0.15	0.01
Temperature, °C																
Pre-handling	39.17	39.29	38.99	39.04	39.40	39.44	39.16	39.18	0.13	-	0.78	-	-	0.01	0.49	-
Post-handling	40.00	40.08	40.00	40.00	40.99	41.33	40.91	41.24	0.18	0.86	0.80	0.80	0.14	0.50	0.06	0.01
Difference	0.83	0.79	1.01	0.96	1.60	1.89	1.75	2.06	0.17	0.94	1.00	0.94	0.06	0.07	0.16	0.01

[a]Values are means 8 observations (pigs) with 2 pigs/pen (handling group.

Table 4. Interactive Effects of L-carnitine, Paylean, and Handling on Heart Rate of Finishing Pigs (Exp. 1)

	Handling															
	Gentle				Non-gentle											
	L-carnitine, ppm															
	0		50		0		50									
	Paylean, ppm									Probability ($P <$)						
Item	0	20	0	20	0	20	0	20	SED	L-carnitine × Paylean × Handling	L-carnitine × Paylean	L-carnitine × Handling	Paylean × Handling	L-carnitine	Paylean	Handling
Heart rate																
Minimum	118	114	121	132	118	137	118	123	12.53	0.18	0.99	0.11	0.38	0.75	0.11	0.73
Average	192	184	193	200	204	210	230	217	11.14	0.09	0.82	0.19	0.09	0.56	0.11	0.01
Maximum	251	247	258	264	279	281	275	289	10.79	0.93	0.22	0.28	0.42	0.15	0.35	0.01
Change (max-min)	133	133	138	132	164	141	153	167	13.19	0.10	0.20	0.66	0.92	0.46	0.56	0.01
Observations/trt	6	8	5	7	6	6	4	4								

Table 5. Interactive Effects of L-carnitine, Paylean, and Handling on Stress Criteria of Finishing Pigs (Exp. 2)[a]

	Gentle Handling				Non-gentle Handling											
	L-carnitine, ppm															
	0		50		0		50									
	Paylean, ppm									Probability ($P <$)						
Item	0	20	0	20	0	20	0	20	SED	L-carnitine × Paylean × Handling	L-carnitine × Paylean	L-carnitine × Handling	Paylean× Handling	L-carnitine	Paylean	Handling
LDH, U/L																
Post-handling	475.75	621.13	457.13	531.63	509.13	560.25	541.88	637.25	29.53	0.23	0.69	0.08	0.41	0.86	0.01	0.13
1hr Post-handling	462.50	588.25	451.38	528.50	599.88	623.38	594.13	708.13	28.13	0.15	0.66	0.12	0.49	0.93	0.01	0.01
Difference	4.75	-32.88	-5.75	-3.13	90.75	63.13	52.25	70.88	19.74	0.94	0.28	0.53	0.74	0.88	0.58	0.01
Lactate, mmol/L																
Post-handling	2.78	5.94	4.10	5.08	19.38	20.43	18.90	22.24	2.36	0.29	0.98	0.84	0.95	0.67	0.05	0.01
1hr Post-handling	2.61	2.73	2.89	2.29	9.54	10.23	10.25	14.50	1.84	0.13	0.31	0.07	0.06	0.09	0.12	0.01
Difference	-0.16	-3.21	-1.21	-2.79	-9.84	-10.20	-8.65	-7.74	1.99	0.96	0.51	0.31	0.22	0.47	0.33	0.01
pH																
Post-handling	7.46	7.42	7.44	7.43	7.13	7.07	7.10	7.03	0.04	0.56	0.74	0.50	0.33	0.43	0.02	0.01
1hr Post-handling	7.42	7.44	7.43	7.44	7.38	7.40	7.38	7.33	0.02	0.42	0.27	0.25	0.49	0.36	0.96	0.03
Difference	-0.04	0.02	-0.01	0.00	0.25	0.34	0.27	0.30	0.02	0.89	0.08	0.66	0.57	0.98	0.01	0.01
Glucose, mg/dL																
Post-handling	84.25	72.38	86.38	80.88	168.88	149.63	156.63	152.63	10.43	0.70	0.35	0.39	0.80	0.95	0.09	0.01
1hr Post-handling	88.25	78.25	86.25	81.00	100.38	76.63	73.13	75.75	4.21	0.21	0.07	0.09	0.73	0.11	0.04	0.64
Difference	4.00	5.88	-0.13	0.13	-68.50	-73.00	-83.50	-76.88	10.48	0.57	0.67	0.69	1.00	0.20	0.85	0.01
Urea nitrogen, mg/dL																
Post-handling	14.75	13.13	13.50	11.88	20.25	12.25	15.38	13.38	0.87	0.04	0.04	0.65	0.02	0.03	0.01	0.03
1hr Post-handling	15.50	13.75	14.38	12.75	21.00	12.25	14.88	13.50	0.87	0.01	0.01	0.19	0.02	0.01	0.01	0.18
Difference	0.75	0.63	1.38	0.88	0.75	0.00	-0.50	0.13	0.26	0.11	0.35	0.07	0.64	0.81	0.48	0.01
Cortisol, ng/ml																
Post-handling	34.46	38.48	38.42	40.16	42.11	37.92	42.90	56.03	3.85	0.07	0.16	0.21	0.76	0.02	0.17	0.08
1hr Post-handling	20.99	32.12	19.47	25.33	58.74	59.48	61.18	69.49	6.37	0.42	0.89	0.20	0.62	0.80	0.11	0.01
Difference	-13.47	-6.35	-18.95	-14.83	16.63	21.56	18.27	13.46	6.63	0.61	0.34	0.57	0.41	0.13	0.40	0.01
Temperature, °C																
Post-handling	40.30	40.47	40.17	40.63	41.03	41.02	40.88	41.46	0.15	0.42	0.02	0.51	0.87	0.40	0.01	0.01
1hr Post-handling	39.45	39.67	39.31	39.71	40.44	40.30	39.84	40.56	0.21	0.20	0.06	0.67	0.95	0.41	0.03	0.01
Difference	-0.85	-0.79	-0.85	-0.93	-0.60	-0.72	-1.04	-0.90	0.19	0.39	0.76	0.30	0.95	0.10	1.00	0.83

[a]Values are means of 8 observations (pigs) with 2 pigs/pen (handling group).

Swine Day 2004

USING MIXER EFFICIENCY TESTING TO EVALUATE FEED SEGREGATION IN FEED LINES

C. N. Groesbeck, R. D. Goodband, M. D. Tokach, J. L. Nelssen, and S. S. Dritz[1]

Summary

An experiment was conducted to evaluate potential diet segregation in feed lines by measuring coefficient of variation (CV) and mean salt concentration. The facility was a 1500-head gestation barn with nine feed lines, transected by a central feed line that conveyed feed from one of two bulk bins. Quantab® chloride titrators were used to analyze the chloride concentration (salt) from samples collected at pre-determined feed line locations at various distances from the bulk bins. Thirty samples were collected from three feed lines (row 1, 5, and 9), ten samples were collected from drop boxes close to the central feed line (location 1), ten samples were collected from a central location within the row (location 2), and ten samples were collected from the furthest end of the feed line (location 3). Samples of approximately 50 g were collected directly from the feed drop. The sample collection procedure was repeated four times. After the first two sample collections, a bin agitator was added to the bulk bin. There was a feed line × distance (within the feed line) × agitator interaction ($P > 0.02$) observed for CV. The addition of the bin agitator improved the CV in feed line 1 and 5, with no improvement observed in feed line 9. The CV observed before the addition of the agitator averaged 17.6, 18.6, and 14.3% for feed lines1, 5, and 9, respectively, and the CV observed after the addition of the agitator averaged 13.6, 16, and 14% for feed line 1, 5, and 9 respectively. Within all feed lines (rows), distance CV was higher at locations 1 (17.3%) and 3 (17.6%), compared with CV at location 2 (15.6%) before the addition of the agitator, but was lower at locations 1 (14.3%) and 3 (13.0%), compared with CV at location 2 (15.6%) after the addition of the agitator. There was a mean-salt concentration effect ($P<0.0001$) observed for feed line. Feed lines 1 and 5 were similar in mean salt concentration, whereas feed line 9 consistently had the highest salt concentration. There was little to no feed segregation observed.

(Key Words: Feed Segregation, Mixer Efficiency, Pigs.)

Introduction

It is ideal to supply animals with the correct ingredient ratios (Ca:P), vitamins, and minerals to maximize production and efficiency. There is sometimes a concern in facilities with long feed lines that feed segregation may be taking place. Coefficient of variation (CV) is often used in the determination of mixer efficiency, and our objective was to use the concept

[1]Food Animal Health and Management Center.

of mixer-efficiency testing to help determine feed segregation in feed lines. A CV of ≤10% for mixer efficiency is considered excellent, a CV of 10 to 15% is an indicator of good mixing, a CV of 15 to 20% is fair, and a CV of 20% or greater indicates insufficient mixing and warrants attention. These CV values were used to determine feed segregation in feed lines, with a smaller CV value indicating less segregation. The most common test for determining CV in mixer efficiency is chloride Quantab® titrators (Environmental Testing Services, Elkhart, IN), which was the analytical method used in our experiment to determine CV for feed segregation in feed lines.

Procedures

The experiment was conducted at a 1500-head gestation barn with nine feed lines, transected by a central feed line conveying feed from one of two bulk bins to feed lines, filling drop boxes. Thirty samples were collected from drop boxes in three feed lines (row 1, 5, and 9) with ten samples collected (from ten adjacent feed drops) at each of the three pre-determined locations (Figure 1). The locations were close to the central feed line (location 1), a central location within the feed line (location 2), and the farthest point from the central feed line (location 3). Samples of approximately 50 g were collected directly from the feed drop. Four sets of samples were collected, two sets before the addition of a feed agitator to the bulk bin and two sets after the addition of the agitator. Ten samples were also collected from the mixer and from the truck as it was unloading the feed into the empty bulk bin before each set of sample collections from the gestation-barn drop boxes. Coefficients of variation were determined with Quantab® chloride titrators, and CV was used to determine feed segregation. For each 10 adjacent samples there was one CV value generated, with three CV values per feed line (row). Ten grams of the collected sample was weighed into a 120-mL sample cup. Ninety ml of 100°C distilled water was poured into the 120-mL sample cup. The sample was stirred for 30 s, let stand for 60 s, and stirred for an additional 30 s. A folded, circular, fast-flow 12.5-cm filter paper (Quantitative Q8) was placed into the 120-ml sample container, and the Quantab® chloride titrator was placed inside of the filter paper. The solution was allowed to completely saturate the wick of the titrator. The reaction was completed when the yellow wick turned completely black. The titrator was removed from the solution, read, and recorded. Coefficient of variation was calculated. All data was analyzed by using PROC MIXED in SAS 8.1.

Results and Discussion

The average CV and mean salt concentration for the samples collected from the mixer were 14% and 0.60, respectively, for the first two sets and 8% and 0.58, respectively, for the second two sample sets. The average CV and salt concentrations for the samples collected as feed was unloading into the bulk bin were 10% and 0.70, respectively, for the first two sample sets and 11% and 0.72, respectively, for the two sets of samples collected after the addition of the agitator. These values indicate a uniformly mixed feed.

There was a feed line × distance (within the feed line) × agitator interaction ($P>0.02$) observed for CV. The addition of the agitator improved the CV in feed lines 1 and 5, with no improvement observed in feed line 9 (Table 1). The CV observed before the addition of the agita-

tor averaged 17.6, 18.6, and 14.3% for feed lines 1, 5, and 9, respectively, and the CV observed after the addition of the agitator averaged 13.6, 16, and 14% for feed lines 1, 5, and 9, respectively. Distance CV was higher at locations 1 (17.3%) and 3 (17.6%), compared with the CV at the center location 2 (15.6%) before the addition of the agitator, but was lower at locations 1 (14.3%) and 3 (13.0%), compared with the CV at the center location 2 (15.6%) after the addition of the agitator. Mean salt concentration was greater ($P<0.0001$) for feed line 9 than for feed lines 1 and 5, which were similar in mean salt concentration (Table 2).

Feed segregation could be a potential problem, especially when feed is being transported long distances from bulk bins in feed lines. Segregation is variable within each system, and some systems could experience more segregation than other systems, based on system maintenance and feed ingredients used. Using the mixer-efficiency testing method, we were able to evaluate the salt concentration of the diet at locations throughout the barn. We used the CV value to determine if segregation of feed ingredients was occurring in the feed lines. If the CV values were consistent throughout the feed lines there would be no segregation occurring, but if changes occurred, then it is possible that some segregation was occurring. The CV results generated were fairly consistent, but they did have some variability. The addition of the agitator did decrease the CV value slightly, from a mean of 16.6 ± 1.8 to 14.5 ± 1.3. Both of the previously listed values are more than the ideal CV value of 10%, but are between 10 and 20%. A CV between 10 and 20% would probably produce results in performance and efficiency similar to a CV of 10%, but the possibility of reducing performance increases as CV is increased. A CV of 20 or more would have a greater probability of affecting animal performance and would need to be addressed.

The mixer-efficiency testing procedure is simple to perform and generates results that are easily interpreted. The procedure could be used to help determine feed-segregation issues within feeding systems.

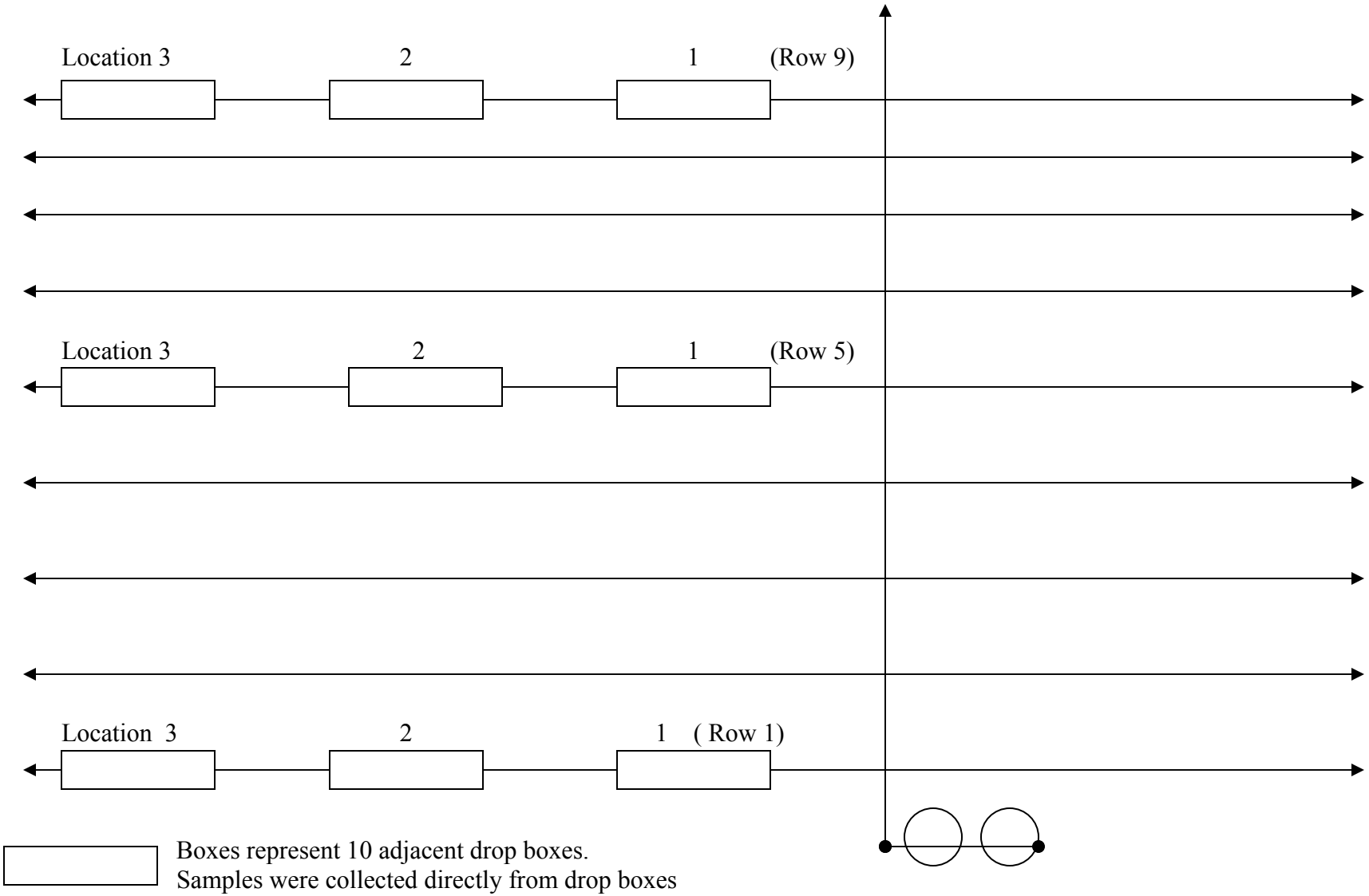

Figure 1. Diagram of Feed Line and Sample Collection Locations, the Facility is a 1500-Head Gestation Barn with 9 Feed lines Transected by a Central Feed Line that Conveyed Feed to the Feed Lines from One of Two Bulk Bins.

Table 1. Coefficient of Variation, %[a]

	Location, distance[b]					
	Before Agitator[c]			After Agitator		
	1[c]	2	3	1	2	3
Feed line 1[d]	22	13	18	14	15	12
Feed line 5	14	17	25	16	18	14
Feed line 9	16	17	10	13	16	13

[a]Coefficient of Variation values were generated from the average of two sets of ten samples collected from adjacent feed drops.
[b]Location 1 – closest set of ten samples to the center feed line; location 2 – ten samples collected from the center location in the feed line; location 3 – the farthest set of ten samples collected form the center feed line.
[c]Two sets of samples (90 samples total, 30 from each feed line, and ten from each distance within the feed line) were collected before the addition of the agitator, and an additional two sets were collected after the agitator was added to the bulk bin.
[d]Feed line 1- closest feed line to the bulk bin; feed line 5 – center feed line; feed line 9 – farthest feed line from the bulk bin.

Table 2. Mean Salt Concentration, %[a]

	Location, distance[b]					
	Before Agitator[c]			After Agitator		
	1	2	3	1	2	3
Feed line 1[d]	0.49	0.48	0.49	0.58	0.52	0.52
Feed line 5	0.51	0.48	0.43	0.40	0.45	0.57
Feed line 9	0.65	0.72	0.67	0.67	0.73	0.73

[a]Mean of salt concentration values were generated form the average of two sets of ten samples collected from adjacent feed drops.
[b]Location 1 – closest set of ten samples to the center feed line; location 2 – ten samples collected from the center location in the feed line; location 3 – the farthest set of ten samples collected form the center feed line.
[c]Two sets of samples (90 samples total, 30 from each feed line, and ten from each distance within the feed line) were collected before the addition of the agitator, and an additional two sets were collected after the agitator was added to the bulk bin.
[d]Feed line 1- closest feed line to the bulk bin; feed line 5 – center feed line; feed line 9 – farthest feed line from the bulk bin.

Swine Day 2004

EFFECTS OF SALT PARTICLE SIZE AND SAMPLE PREPARATION ON RESULTS OF MIXER-EFFICIENCY TESTING

C. N. Groesbeck, R. D. Goodband, M. D. Tokach, S. S. Dritz[1], J. L. Nelssen, and J. M. DeRouchey

Summary

Two experiments were conducted to evaluate the effects of using salt with different particle sizes and of using different sample-preparation methods on mixer-efficiency testing (time required to achieve a coefficient of variation (CV) of 10% or less among 10 feed samples). A 3000-lb capacity horizontal ribbon mixer was used to mix batches of feed. Ten samples were collected at eight times during mixing (0.0, 0.5, 1.0, 2.0, 3.5, 5.5, 8.0, and 10.5 min) after all ingredients were added from pre-determined locations in the mixer. Coefficient of variation was used to measure mixer efficiency by analysis for chloride concentration in each sample with Quantab® chloride titrators. In Exp. 1, four 3000-lb batches of feed were prepared, two with 440-micron salt and two with 730-micron salt. Samples were analyzed as collected (unground; approximately 700 microns) or were ground with a coffee grinder (ground; approximately 400 microns). A salt particle size × sample preparation × mixing time interaction ($P<0.001$) was observed, but a CV of 10% or less was never achieved, indicating inadequate mixing. In Exp. 2, all samples were collected from 2000-lb batches of feed made in the 3000-lb-capacity mixer. Four different salt particle sizes (440, 730, 1999, and 3000 micron) were used, and each set of samples collected was also analyzed as unground or ground. A salt particle size × sample preparation × mixing time interaction ($P<0.04$) was observed. As salt particle size decreased and mixing time increased, there was a decrease in CV. Grinding samples before analysis decreased CV, compared with that of the unground samples, but to a greater extent with coarse salt than with fine salt. The batch mixed with 440-micron salt and the batch mixed with 730-micron salt (ground) reached a CV of less than 10%, indicating a uniform mixture. No other treatments reached a CV of 10% or less. When the mixer was filled to the rated capacity we were unable to achieve an acceptable CV for mixer efficiency; therefore, it is important to test mixers at various fill levels. Our study also showed that it is important to use a fine mixing salt when testing mixers for mixer efficiency.

(Key Words: Mixer Efficiency, Particle Size, Pigs, Salt.)

Introduction

The purpose of mixing a livestock diet is to distribute all ingredients and nutrients throughout the entire batch of feed to achieve a uniform mixture. A uniform mixture will supply the animal with a balanced diet, ensure proper nutrient consumption, and maximize animal performance. Testing uniformity within batches of feed is commonly termed mixer-efficiency testing. Briefly, mixer-efficiency

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testing consists of obtaining multiple samples from a batch of feed, analyzing for the selected ingredient, and evaluating the within-batch variability. The results for mixer-efficiency testing are often reported as a coefficient of variation (CV), which is the standard deviation divided by the mean. Standard guidelines for evaluating CV are: A CV of less than 10% is considered excellent; a CV of 10 to 15% is considered good mixing that may be an indicator that increased mix time is needed, and a CV greater than 15% warrants finding a cause of the poor mixing efficiency. The selected ingredient or tracer should have low analytic variability, and the analysis should be relatively inexpensive to perform, because multiple samples need to be analyzed to characterize within-batch variability. Salt is the most common ingredient used to evaluate mixer efficiency. But a variety of particle sizes of salt are used in swine diets. Because only a small subsample of feed is tested for each feed sample, we hypothesize that a larger particle size of salt may increase analytic variability. This would artificially increase the CV in a well-mixed diet. One method to reduce analytic variability in samples with variability in particle size is to finely grind the sample. Therefore, the objective of our study was to determine whether salt particle size or sample-preparation method influence the mixing time required to achieve a CV of less than 10%.

Procedures

Both experiments were conducted at the Kansas State University Animal Sciences and Industry Feed Mill in a 3000-lb-capacity, horizontal, double-ribbon paddle mixer (DS30, Davis & Sons Manufacturing Company, Bonner Springs, KS). A basal diet was used to collect all samples. The diet contained 67.3% sorghum (680 microns), 30% soybean meal (700 microns), 1.0% limestone (180 microns), 0.9% monocalcium phosphate (540 microns), 0.15% L–Lysine HCl (680 microns), 0.15% trace mineral premix (320 microns), 0.15% vitamin premix (300 microns) and 0.35% salt. For each batch of feed made, ten samples were collected at eight mixing times (0.0, 0.5, 1.0, 2.0, 3.5, 5.5, 8.0, and 10.5 min), resulting in a total of 80 samples per batch. All ten samples were collected from pre-determined locations in the mixer, by using a grain probe. Samples were placed into pre-labeled sample bags. Coefficient of variation (CV) was used to measure mixer efficiency, and was determined by analysis for dietary chloride concentration with a standard analytic test kit (Quantab® chloride titrators; Environmental Test System, Elkhart, IN). Ten g of the collected sample was weighed into a 120-mL sample cup. Ninety mL of 100°C distilled water was added to the sample cup. The sample was stirred for 30 s, let stand for 60 s, and stirred for an additional 30 s. A folded, circular, fast-flow 12.5-cm filter paper (Quantitative Q8, Pittsburg, PA) was placed into the 120-mL sample container, and the Quantab® chloride titrator was placed inside of the filter paper. Solution was allowed to completely saturate the wick of the titrator. The reaction was completed when the yellow wick turned completely black. The titrator was removed from the solution, read, and recorded. Coefficient of variation was then calculated for each batch and replicate. All data were analyzed by using PROC MIXED in SAS 8.1 (SAS Inst. Inc., Cary, NC).

Experiment 1. The objective was to evaluate the effects of two salt particle sizes (440 and 730 microns) and of grinding the test sample on mixer efficiency (time required to achieve a CV of 10% or less, among 10 feed samples). All samples in Exp. 1 were collected from 3000-lb batches of feed in a 3000-lb-capacity mixer. Four batches of feed were made, two for each particle size of salt. Each batch of feed collected also was analyzed as collected (unground) and analyzed after being ground in a coffee grinder (Model 168940, General Electric).

Experiment 2. The objective was to further evaluate the effects of salt with different particle sizes and of using different sample-preparation methods on mixer efficiency. All samples in Exp. 2 were collected from 2000-lb batches of feed, mixed in the 3000-lb-capacity mixer used in Exp. 1. We evaluated salt with four different particle sizes (440, 730, 1999, and 3000 microns). Eight batches of feed were made, two for each salt particle size. Similar to Exp. 1, in Exp. 2 each batch of feed collected was also analyzed as collected (unground) and analyzed after being ground to approximately 400 microns in a coffee grinder.

Results and Discussion

Experiment 1. A salt particle size × sample preparation × mixing time interaction ($P < 0.001$) was observed (Figure 1). For the first 2.0 min of mixing, the coefficient of variation dropped rapidly, with ground samples mixed with 730-micron salt having a lower CV than the unground samples, and no difference in sample preparation in the samples mixed with 440-micron salt. Also, as time increased, there was an improvement in mixing performance, but a CV of 10% or less was never achieved. Because a CV of 10% or less was not achieved, it is possible that the mixer was overfilled when filled at the rated capacity (3000 lb); therefore, we used 2000-lb batches in Exp. 2.

Experiment 2. A salt particle size × sample preparation × mixing time interaction ($P<0.04$) was observed (Figure 2). As salt particle size decreased and mixing time increased, there was a decrease in CV. When samples were ground before Quantab® analysis, there was a decrease in CV, and differences between ground and unground smaples became less when smaller-particle salt was used. Similar to Exp. 1, in Exp. 2 the CV of samples mixed with the 440-micron salt showed no improvement with grinding. Unlike Exp. 1, in Exp. 2 the samples mixed with the 440- and 730-micron salt reached a CV of less than 10% when ground, indicating a uniform mixture. No other treatments reached a CV of 10% or less.

Mixer-efficiency evaluation of mixers should be conducted on a regular basis. Every mixer is variable in mixing time and, as it ages, mixing time may have to be altered to ensure that adequate mixing is occurring. There are several methods that can be used to test mixer efficiency. Quantab® chloride titrators were used in Exp.1 and 2 because the assay is simple to conduct and inexpensive. Previous research with Quantab® analysis has also shown that the Quantab® assay is comparable to both a salt-meter test and laboratory analysis and is less expensive to perform.

The salt with a particle size of 440 microns mixed to a CV of less than 10% in 2.0 min in the 2000-lb batch, and never achieved an adequate CV when the mixer was filled to the rated capacity of 3000 lb. This suggests that filling the tested mixer at rated capacity inhibits the mixing action and increases the time needed to adequately mix. Previous research also has indicated that many mixers do not operate efficiently when filled to the rated capacity.

The particle size of ingredients can affect the time needed to adequately mix feed to a uniform end point. Salt with particle sizes of 440 and 730 microns was used in both experiments. In Exp. 2, it was demonstrated that, as the particle size of salt increased, the time needed to achieve a uniform mixture increased. With ingredients being variable in size and shape, ingredient selection becomes more important. The particle sizes and shapes of all ingredients should be similar to ensure proper dispersal throughout the feed.

Experiments 1 and 2 demonstrated that when samples are analyzed as collected (un-ground), the CV may be overestimated by the

analysis, compared with that of the samples analyzed after grinding to a uniform particle size. Although the results from samples mixed with 440-micron salt were very similar between the as-collected (unground) and ground samples, the decrease in CV to 10% or less indicates that a fine mixing salt should be used when mixer-efficiency analysis is being conducted. The fine mixing salt will provide the most accurate CV. If a coarse salt is used in mixer efficiency testing, grinding the sample to a uniform particle size before analysis will give a better indication of the performance of the mixer, but using a fine mixing salt will still generate more accurate results.

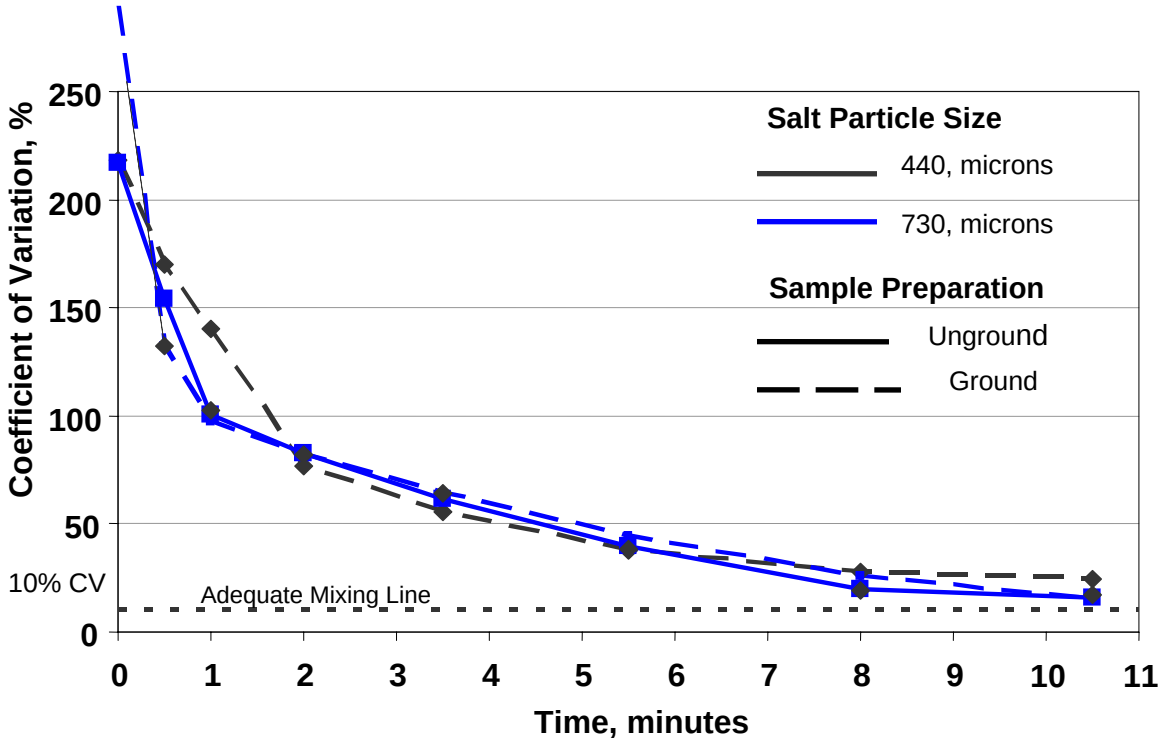

Figure 1. There was a Salt Particle Size × Sample Preparation × Mixing Time Interaction (P<0.001) Observed. For the first 2.0 min of mixing, the coefficient of variation dropped rapidly. Grinding the samples mixed with 730-micron salt resulted in a lower CV than the unground samples had, no difference among the samples mixed with 440-micron salt. A CV of 10% or less was never achieved in Exp. 1, indicating that we were unable to achieve a uniform mixture.

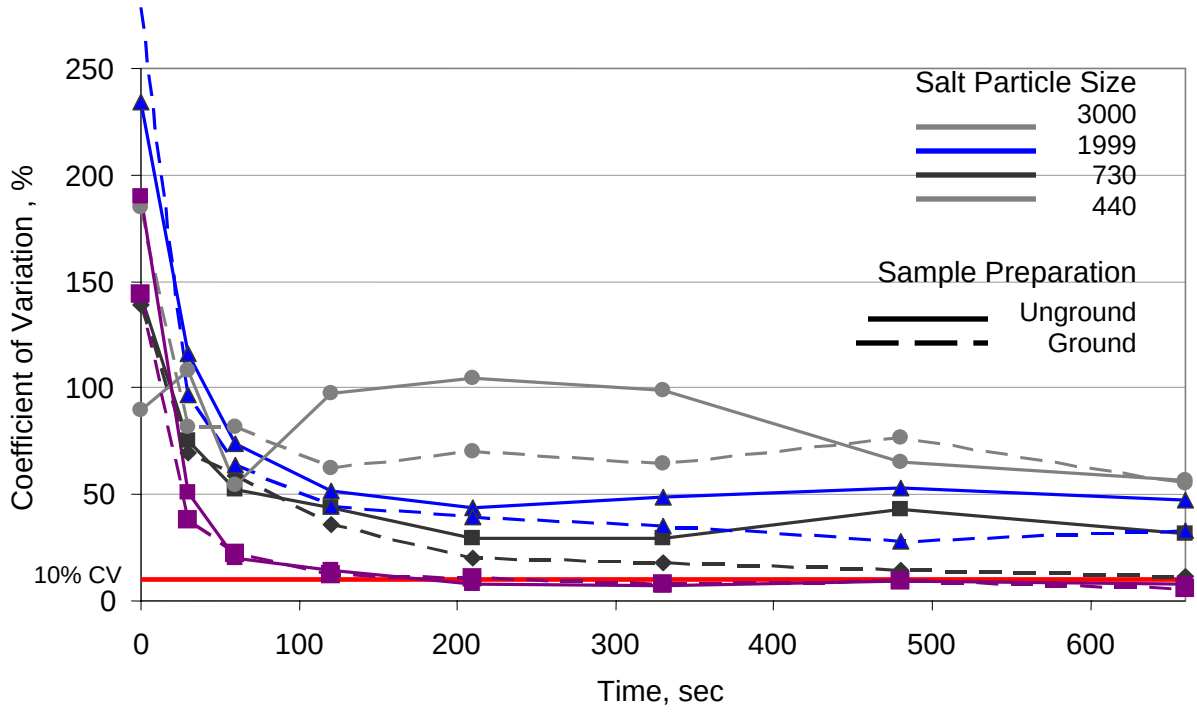

Figure 2: There was a Salt Particle Size × Sample Preparation × Mixing Time Interaction (P<0.04) Observed. As salt particle size decreased and mixing time increased, there was a decrease in CV. When samples were ground before Quantab® analysis, there was a decrease in CV. The samples mixed with 440-micron salt showed no improvement with grinding. The samples mixed with 730-micron salt (ground) and the 440-micron salt (ground and unground) reached a CV of less than 10%, indicating a uniform mixture. No other treatments reached a CV of 10% or less.

Swine Day 2004

EVALUATION OF TOPICAL ANTIOXIDANTS AND PACKAGING MATERIALS TO DECREASE THE INCIDENCE OF BONE DISCOLORATION IN PORK RETAIL CUTS

C. R. Raines and M .E. Dikeman

Summary

Color characteristics were evaluated on 48 pork backbones. After 6 d postmortem, six 1-inch-thick sections of lumbar vertebrae were cut from each backbone. Lumbar vertebrae were treated with different concentrations of ascorbic acid, with combination treatments of ascorbic acid and natural antioxidants, or left untreated. Bones were packaged in one of three systems: high-oxygen modified-atmosphere packaging (MAP), ultra-low-oxygen MAP, or polyvinyl chloride (PVC) overwrap trays. Bones were visually evaluated by a trained panel on d 0, 1, 2, 3, 4, 5, and 8. Lightness (L*) was also measured on d 0, 2, and 8 of display. After 8 d of display, antioxidant-treated bones packaged in high-oxygen MAP were more desirable than those in PVC overwrap trays. Bones packaged in ultra-low-oxygen MAP became less desirable over 8 d of display. Solutions of 1.875% and 2.50% ascorbic acid yielded the most desirable color after 8 d for bones in high-oxygen MAP and in PVC overwrap trays. Bones treated with 1.875% or 2.50% ascorbic acid tended to have lighter color (higher L*) on d 8 for high-oxygen MAP and PVC overwrap trays, whereas an overall difference was not observed for lightness for bones packaged in ultra-low-oxygen MAP.

(Key Words: Bone Color, Modified Atmosphere Packaging, Antioxidant, Pigs.)

Introduction

Bone color in fresh retail cuts is important to consumers. High-oxygen MAP and PVC overwrap trays are packaging methods conducive to red color development, but bone discoloration or darkening can be a problem in these systems. It has been shown that feeding antioxidants to livestock, and the application of antioxidants in processing, both can inhibit bone darkening. Recent research at Kansas State University has shown that the application of 2.50% ascorbic acid minimizes beef bone discoloration within these packaging systems. The objective of this study was to evaluate the effects of topical antioxidants on the development of bone discoloration and/or darkening in pork lumbar vertebrae packaged by using three different packaging systems.

Procedures

Forty-eight pork backbones from 1 day's kill were obtained from a commercial abattoir, from which six 1-inch-thick sections of lumbar vertebrae were cut at 6 d postmortem by using a band saw and were brushed to remove bone dust. One cut section from each backbone was treated with a 0.5-mL aliquot of one of five treatments: 1.25%, 1.875%, or 2.5% ascorbic acid solution (L-ascorbic acid, Sigma-Aldrich, St. Louis, MO); a combination treatment of 0.15% Origanox™ WS (Rad Natural Technologies Ltd., Tikva, Israel) and 0.30% ascorbic acid solution; or 0.225% Origanox™ WS and 0.45% ascorbic acid. The sixth section was used as the control, with no treatment applied. Bones were packaged such that the six vertebral pieces represented all six treatments and came from the same backbone.

Three packaging systems were used: high-oxygen (80% O_2, 20% CO_2) MAP; ultra-low-oxygen (70% N_2, 30% CO_2) MAP containing an activated oxygen scavenger; and

polyvinyl chloride (PVC) overwrap. High-oxygen and ultra-low-oxygen packages were packaged in rigid trays and covered with barrier lidding film. The PVC samples were packaged in foam trays with oxygen permeable film.

Packages were displayed under continuous fluorescent lighting (2153 lux, 300K and CRI=85, Bulb Model F32T8/ADV830/Alto, Phillips, Bloomfield, NJ) for 8 d at 2°C in a retail display case. Packages were rotated twice daily to maintain random display-case placement.

Six trained visual panelists scored bone marrow color once a day on six days beginning on d 0 (d 0 to d 5), and also once on d 8 of the display period. A seven-point scale was used for high-oxygen MAP and PVC packages: 1) bright reddish-pink to red, 2) dull reddish-pink, 3) slightly grayish-pink or -red, 4) grayish-pink or -red, 5) moderately gray, 6) all gray or grayish-black, and 7) black discoloration. Ultra-low-oxygen MAP samples were scored according to a different seven-point scale, and ultra-low-oxygen meat tends to have a more "purplish" color than red color: 1) bright purplish-red or -pink, 2) dull purplish-red or -pink, 3) slightly grayish-purple or -pink, 4) grayish-purple or -red, 5) moderately gray, 6) all gray or grayish-black, and 7) black discoloration. Both scales were used in half-point increments, and panelists were instructed to score the porous portion of the bone marrow.

Instrumental CIE L* measurements were taken twice on each cut vertebral section by using a 0.25-inch aperture (Illuminant A) with a Hunter Labscan 2 (Hunter Associates Laboratory, Inc., Reston, VA), and then averaged. Instrumental measurements were taken from all samples on d 0, from 24 opened packages on d 2, and from 24 opened packages on d 8. Those measured on d 2 were reserved strictly for that purpose, and those on d 8 were also those scored by the visual panel. L* corresponds to lightness, where a higher L* value equates to lighter color.

The data were analyzed with SAS PROC MIXED (SAS Instutute, Inc., Cary, NC). Pairwise comparisons of least squares means were used to determine significant differences ($P<0.05$).

Results and Discussion

There was an interaction for visual color between packaging type, day, and antioxidant treatment for lumbar vertebrae packaged in PVC overwrap and in high-oxygen MAP. Because the same color scale was used, those packaging systems can be compared. Ultra-low-oxygen MAP used a different color scale than PVC and high-oxygen MAP did, thus barring comparison. For Ultra-low-oxygen, there was only a day effect.

Control lumbar vertebrae packaged in PVC and high-oxygen MAP did not exhibit ($P<0.05$) graying until d 3 and d 4 of display, respectively (Table 1). From d 2 to d 8, antioxidant-treated lumbar vertebrae packaged in high-oxygen MAP had better visual scores ($P<0.05$). By d 5 of display, lumbar vertebrae packaged in PVC and treated with either of the Origanox™-ascorbic acid treatments or 1.25% ascorbic acid exhibited ($P<0.05$) graying, whereas like-treated bones packaged in high-oxygen MAP did not. By d 5, the least desirable ($P<0.05$) lumbar vertebrae was the PVC-packaged control. Antioxidant-treated bones packaged in high-oxygen MAP had the most desirable ($P<0.05$) visual color on d 5. On d 8 of display in high-oxygen MAP, samples treated with higher concentrations of ascorbic acid alone had visual color scores superior ($P<0.05$) to those of samples treated with the Origanox™-ascorbic acid; the color scores of samples treated with 1.25% ascorbic acid were intermediate ($P<0.05$) (Table 1). All antioxidant-treated lumbar vertebrae in high-oxygen MAP had superior ($P<0.05$)

color scores to those in PVC trays. Control lumbar vertebrae packaged in high-oxygen MAP exhibited the least-desirable ($P<0.05$) visual color on d 8. For PVC-packaged bones, treatments with 1.875% or 2.50% ascorbic acid yielded better ($P<0.05$) visual color values on d 8 than did other treatments.

Visual color scores of lumbar vertebrae packaged in ultra-low-oxygen MAP declined ($P<0.05$) from d 0 to d 3, and stabilized from d 3 to d 5 of display (Table 2). The least-desirable ($P<0.05$) visual color score was on d 8.

L* values correspond to lightness, and higher L* values indicate lighter-color samples. For all lumbar vertebrae packaged in high-oxygen MAP, L* values increased ($P<0.05$) from d 0 to d 2 and decreased ($P<0.05$) from d 2 to d 8. MAP (Table 3). For PVC-packaged bones, L* values were more similar across treatments. For bones packaged in ultra-low-oxygen MAP and treated with antioxidant, d 0 and d 2 L* values did not differ ($P>0.05$), and were lower ($P<0.05$) on d 8. Control lumbar vertebrae packaged in high-oxygen MAP had the lowest ($P<0.05$) d 8 L* value (the least bright color), and PVC-packaged lumbar vertebrae treated with 1.875% ascorbic acid had the highest ($P<0.05$) d 8 L* value (Table 3). Among lumbar vertebrae packaged in high-oxygen MAP, the 1.875% ascorbic acid had the highest ($P<0.05$) L* value, thus the lightest color. Nominal differences in d 8 L* values were observed among bones packaged in ultra-low-oxygen MAP.

Bones packaged in high-oxygen MAP and treated with higher concentrations of ascorbic acid generally had more desirable visual and instrumental results. Also, it can be seen that bones packaged in high oxygen do need an antioxidant applied. The impact of an antioxidant in ultra-low-oxygen MAP was not observed, however, suggesting that they may not be needed in ultra-low-oxygen systems.

Table 1. Visual Color Scores[a] of Pork Lumbar Vertebrae Displayed for 8 Days in High-Oxygen MAP or PVC Overwrap Packaging

Package Type	Antioxidant Treatment	Day						
		0	1	2	3	4	5	8
High-O_2	0.15% Origanox™ + 0.30% Ascorbic Acid	$1.36^{b,u}$	$1.54^{c,uv}$	$1.75^{de,vw}$	$1.94^{d,wx}$	$2.13^{e,xy}$	$2.25^{f,y}$	$2.76^{f,z}$
High-O_2	0.225% Origanox™ + 0.45% Ascorbic Acid	$1.37^{b,v}$	$1.53^{c,vw}$	$1.72^{e,w}$	$1.98^{d,x}$	$2.14^{e,xy}$	$2.29^{f,y}$	$2.72^{f,z}$
High-O_2	1.25% Ascorbic Acid	$1.35^{b,v}$	$1.51^{c,vw}$	$1.70^{e,wx}$	$1.95^{d,xy}$	$2.07^{e,y}$	$2.18^{f,y}$	$2.59^{fg,z}$
High-O_2	1.875% Ascorbic Acid	$1.34^{b,v}$	$1.48^{c,wv}$	$1.74^{de,w}$	$2.01^{d,x}$	$2.07^{e,xy}$	$2.19^{f,y}$	$2.39^{g,z}$
High-O_2	2.50% Ascorbic Acid	$1.37^{b,v}$	$1.50^{c,vw}$	$1.68^{e,wx}$	$1.94^{d,xy}$	$2.03^{e,yz}$	$2.07^{f,yz}$	$2.24^{g,z}$
High-O_2	Control	$1.23^{b,t}$	$1.65^{bc,u}$	$2.05^{cd,v}$	$2.60^{c,w}$	$3.17^{c,x}$	$3.76^{c,y}$	$4.79^{b,z}$
PVC	0.15% Origanox™ + 0.30% Ascorbic Acid	$1.45^{b,t}$	$1.80^{bc,u}$	$2.29^{bc,v}$	$2.59^{c,w}$	$3.08^{c,x}$	$3.43^{cd,y}$	$3.77^{d,z}$
PVC	0.225% Origanox™ + 0.45% Ascorbic Acid	$1.38^{b,t}$	$1.83^{bc,u}$	$2.33^{bc,v}$	$2.68^{c,w}$	$3.13^{c,x}$	$3.42^{cd,y}$	$3.90^{d,z}$
PVC	1.25% Ascorbic Acid	$1.32^{b,t}$	$1.67^{bc,u}$	$2.18^{bc,v}$	$2.45^{c,w}$	$2.86^{cd,x}$	$3.26^{d,y}$	$3.75^{d,z}$
PVC	1.875% Ascorbic Acid	$1.30^{b,v}$	$1.67^{bc,w}$	$2.20^{bc,x}$	$2.44^{c,x}$	$2.75^{d,y}$	$2.81^{e,y}$	$3.24^{e,z}$
PVC	2.50% Ascorbic Acid	$1.42^{b,v}$	$1.84^{bc,w}$	$2.29^{bc,x}$	$2.48^{c,x}$	$2.77^{d,y}$	$2.90^{e,y}$	$3.39^{e,z}$
PVC	Control	$1.44^{b,u}$	$1.92^{b,v}$	$2.48^{b,w}$	$3.24^{b,x}$	$3.81^{b,y}$	$4.30^{b,z}$	$4.31^{c,z}$

[a]1=bright reddish-pink to red, 2=dull reddish-pink, 3=slightly grayish-pink or -red, 4=grayish-pink or -red, 5=moderately gray, 6=all gray or grayish-black, and 7=black discoloration.
^{b,c,d,e,f,g}Means having different superscript letters within columns differ ($P<0.05$).
^{t,u,v,w,x,y,z}Means having different superscript letters within rows differ ($P<0.05$).
High-O_2 = High-oxygen modified atmosphere packaging (MAP).
PVC = Polyvinyl chloride overwrap trays.

Table 2. Visual Color Scores[a] of Pork Lumbar Vertebrae Displayed for 8 Days in Ultra-Low-Oxygen MAP Packaging, Pooled Across Treatments

	Day						
	0	1	2	3	4	5	8
Score	1.95^{b}	2.32^{c}	2.80^{d}	3.13^{e}	3.41^{e}	3.51^{e}	3.74^{f}

[a]1=bright purplish-red -pink, 2=dull purplish or -pink, 3=slightly grayish-purple or -pink, 4=grayish -purple or -red, 5=moderately gray, 6=all gray or grayish-black, and 7=black discoloration.
^{b,c,d,e,f}Means having different superscript letters differ ($P<0.05$).

Table 3. L* Values of Pork Lumbar Vertebrae Treated with Different Antioxidants and Displayed for 8 Days

Package Type	Antioxidant Treatment	Day		
		0	2	8
High-O_2	0.15% Origanox™ + 0.30% Ascorbic Acid	$48.87^{cd,y}$	$52.71^{abc,z}$	$44.22^{ghi,x}$
High-O_2	0.225% Origanox™ + 0.45% Ascorbic Acid	$49.39^{bcd,y}$	$51.30^{abcd,z}$	$42.36^{hi,x}$
High-O_2	1.25% Ascorbic Acid	$49.42^{bcd,y}$	$53.33^{ab,z}$	$45.30^{efg,x}$
High-O_2	1.875% Ascorbic Acid	$48.79^{cd,y}$	$52.69^{abc,z}$	$48.62^{bc,y}$
High-O_2	2.50% Ascorbic Acid	$48.69^{d,y}$	$53.81^{a,z}$	$45.77^{efg,x}$
High-O_2	Control	$48.60^{d,y}$	$51.49^{abcd,z}$	$41.09^{i,x}$
PVC	0.15% Origanox™ + 0.30% Ascorbic Acid	$49.53^{abcd,y}$	$51.31^{abcd,z}$	$47.15^{cde,x}$
PVC	0.225% Origanox™ + 0.45% Ascorbic Acid	$48.61^{d,z}$	$49.50^{defg,z}$	$46.85^{def,y}$
PVC	1.25% Ascorbic Acid	$48.54^{d,y}$	$50.71^{cde,z}$	$49.42^{ab,yz}$
PVC	1.875% Ascorbic Acid	$49.04^{cd,y}$	$50.67^{cdef,z}$	$50.73^{a,z}$
PVC	2.50% Ascorbic Acid	$49.45^{abcd,z}$	$51.07^{bcde,z}$	$50.02^{ab,z}$
PVC	Control	$48.73^{cd,y}$	$50.56^{cdef,z}$	$48.83^{bc,y}$
U-low-O_2	0.15% Origanox™ + 0.30% Ascorbic Acid	$50.10^{abc,y}$	$48.03^{g,y}$	$44.17^{ghi,z}$
U-low-O_2	0.225% Origanox™ + 0.45% Ascorbic Acid	$51.34^{a,y}$	$48.30^{fg,y}$	$43.89^{ghi,z}$
U-low-O_2	1.25% Ascorbic Acid	$50.59^{abc,y}$	$49.85^{defg,y}$	$44.20^{ghi,z}$
U-low-O_2	1.875% Ascorbic Acid	$51.06^{ab,y}$	$50.71^{cde,y}$	$45.67^{efg,z}$
U-low-O_2	2.50% Ascorbic Acid	$50.67^{ab,y}$	$49.51^{defg,y}$	$44.28^{fg,z}$
U-low-O_2	Control	$51.20^{ab,y}$	$49.15^{efg,y}$	$45.12^{efg,y}$

^{a,b,c,d,e,f}Means having different superscripts within columns differ ($P<0.05$).
^{x,y,z}Means having different superscripts within rows differ ($P<0.05$).
High-O_2 = High-oxygen modified atmosphere packaging (MAP).
PVC = Polyvinyl chloride overwrap trays.
U-Low-O_2 = Ultra-low oxygen MAP.

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Kansas State University Agricultural Experiment Station and Cooperative Extension Service

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