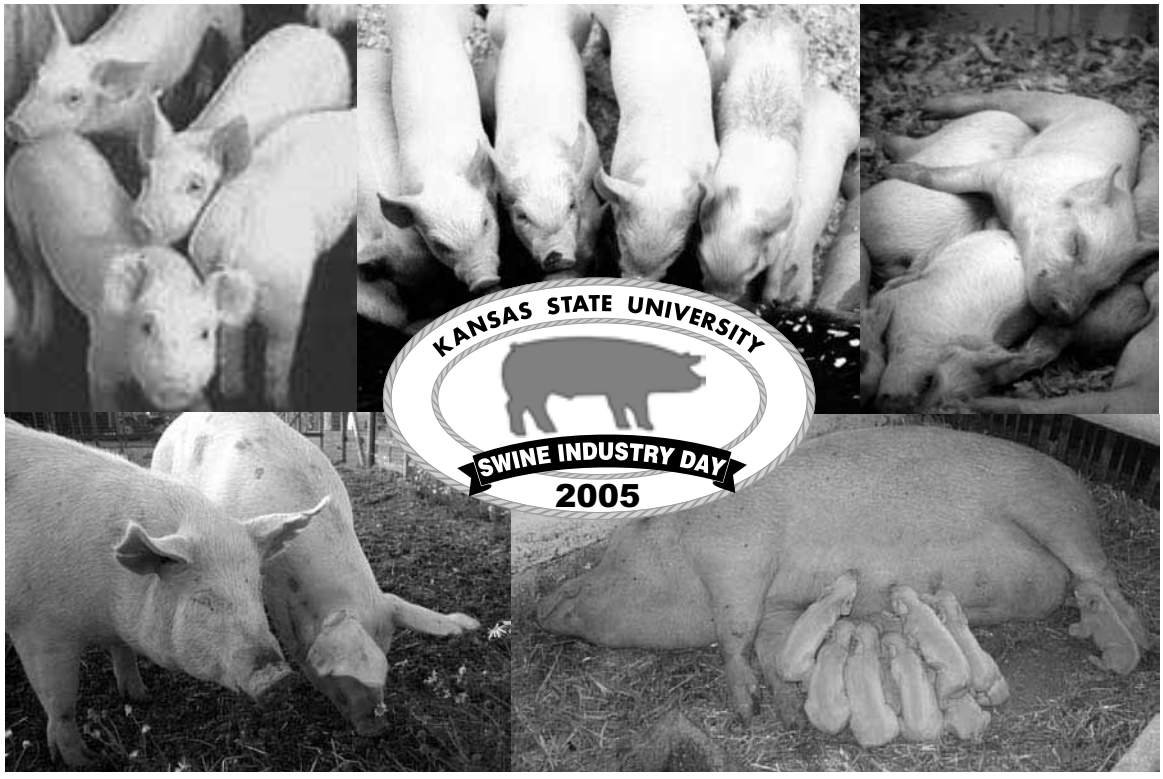
K-STATE
Kansas State University

SWINE RESEARCH 2005



Summary Publication of Report of Progress 964

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

FOREWORD

It is with great pleasure that we present to you Swine Research 2005. 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, 2005 Swine Research,

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 levels and for the use specified in that clearance.

CONTENTS

Gestation, Breeding, and Farrowing Management

Nursery Management

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 higher 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.

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.

A REVIEW OF OXYTOCIN USE FOR SOWS AND GILTS

S. K. Linneen, J. M. Benz, S. S. Dritz[1], J. M. DeRouchey, R. D. Goodband, and M. D. Tokach

Summary

Oxytocin is frequently used to decrease farrowing time and birth interval as an aid to prevent stillbirths, but recent research has shown that oxytocin use can increase the number of pigs stillborn when used too early in the birth process. The research indicated that the reason for increased stillbirths was an increased number of ruptured umbilical cords, leading to compromise of the pigs' oxygen supply during the birth process. Oxytocin usage should be limited to older-parity sows and the last half of the birth order.

(Key Words: Oxytocin, Stillbirth, Farrowing.)

Introduction

Swine producers use oxytocin to shorten farrowing time and the interval between each pig born. A 1995 National Animal Health Monitoring System (NAHMS) study indicates that 8.2% of swine producers administer oxytocin to all sows farrowed. Oxytocin is a hormone produced in the hypothalamus and excreted by the pituitary gland. It has numerous functions, but the two most known are for the milk letdown reflex and for stimulation of uterine contractions. Oxytocin stimulation of uterine contractions will decrease the interval between piglet births, and is used on many farms as an intervention to reduce stillbirths and aid in the farrowing process. But administering oxytocin before the cervix is fully dilated or the first pig is born can lead to dystocia or difficult birth. Improper oxytocin use can also cause an increased number of stillbirths by causing ruptured umbilical cords that lead to decreased oxygen delivery to the piglet during birth.

Discussion

A stillbirth is defined as a piglet that is normally developed but dies shortly after or during parturition and does not breath. Stillbirth numbers are typically higher in older-parity sows, and generally occur later in the birth order. In one study, for example, 75% of stillbirths were recorded after the 8th pig was born when sows were allowed to farrow without intervention. In contrast, this same study indicated that 88% of stillbirths were recorded before the 5th pig was born when sows were administered a single dose of oxytocin after the first pig was born.

An evaluation of the risk factors for stillbirths on two commercial swine farms in Brazil indicated that use of oxytocin increased the risk for stillbirth. A total of 101 litters were evaluated from the first farm, and 373 litters were evaluated on the second farm. The data indicated that the percentage of litters with one or more stillbirths was increased on each of the farms when oxytocin was given to the sow some time during the birth process (Figure 1).

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

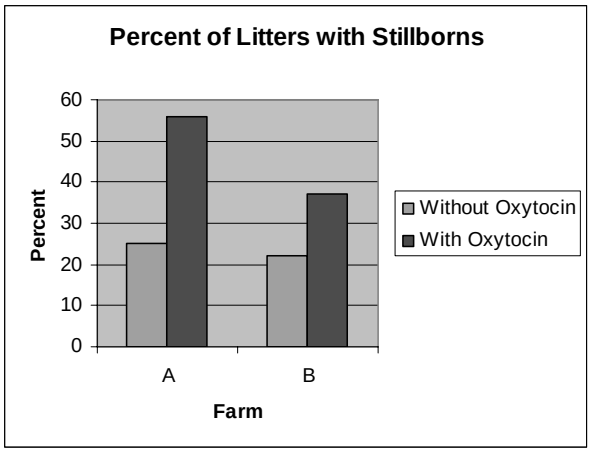


Figure 1. Percentage of Litters from Two Farms with or without Oxytocin Administration. (Adapted from Lucia, T. et al. 2002. Prev. Vet. Med. 53:285-292.)

Data from a prospective study indicated that stillbirths per litter were significantly increased after the administration of a single dose of oxytocin (Table 1). The control sows were allowed to farrow without intervention. The oxytocin group is the mean of two different oxytocin sources; the sows were administered a single dose of oxytocin after the first pig had been born. All births were attended, and the pigs were classified as live or stillborn. Presence of meconium staining and umbilical cord hemorrhage also were evaluated. Meconium staining is an indicator of inspiratory effort, either in the uterus or birth canal, when the piglet has low levels of blood oxygen.

As expected, the total farrowing time and interval between piglet births was reduced in sows administered oxytocin (Table 1). But the numbers of intrapartum stillborn deaths and ruptured umbilical cords per litter were significantly greater among the sows treated with oxytocin than among the control sows. Also, severe meconium staining was more prevalent in live-born and stillborn pigs born of treated sows. Meconium staining is a good indicator that the piglets are oxygen deprived. The study suggests that oxytocin administration was causing umbilical cord injury that compromised delivery of oxygen to the piglet during the birth process, which caused stillbirth deaths.

Although improper use of oxytocin has potentially negative implications, it also can be beneficial to the farrowing process to stimulate uterine contractions and prevent stillbirths in older sows. The recommended dosage is ½ cc (10 IU) to stimulate uterine contraction. Larger doses frequently are used, but larger doses will not improve the efficiency of oxytocin usage. The following are further recommendations for properly using oxytocin:

- Administer oxytocin only after the cervix is fully dilated
- Limit usage in gilt litters
- For a normally farrowing sow, do not use oxytocin until a minimum of 6 pigs have been born
- Use oxytocin when a sow has not had a piglet for more than 40 minutes
- Only use a maximum of two doses per sow

Oxytocin should not be used as a substitute for obstetrical assistance. Indicators of need for obstetrical assistance are bloody discharge from the vulva, no piglets born in at least 40 minutes, obvious pain or straining, or a history of stillbirths.

Table 1. Farrowing Variables of Saline Solution-treated (Control) and Oxytocin-treated Sows[a]

	Sow Group[b]	
Variables	Control	Oxytocin
Farrowing time, min	316.68 ± 9.70	170.145 ± 4.71
Interval between piglet births, min	28.54 ± 0.63	14.37 ± 0.36
Intrapartum stillbirths per litter	0.73 ± 0.13	1.16 ± 0.1
Ruptured umbilical cords per litter	0.15 ± 0.05	0.64 ± 0.095
Inspiratory effort, stillbirths per litter	0.35 ± 0.08	0.05 ± 0.015
Detectable heart rate, stillbirths per litter	0.50 ± 0.10	0.12 ± 0.04

[a]Adapted from D. Mota-Rojas et al., 2002. American Journal of Veterinarian Research 63:1571-1574.

[b]The control sows were allowed to farrow without intervention. The oxytocin group is the mean of two different oxytocin sources when the sows were administered a single dose of oxytocin after the first pig had been born.

PORCINE REPRODUCTIVE AND RESPIRATORY SYNDROME: CHARACTERISTIC FEATURES OF THE INFECTED FETUS[1]

R.R.R Rowland, J Nietfeld, and S. S. Dritz[2]

Summary

Pregnant gilts were infected at 90 days of gestation with porcine reproductive and respiratory virus (PRRSV) isolate SD-23983. Fetuses recovered between 109 and 112 days of gestation were analyzed for the presence of PRRSV. The results showed that not all fetuses were infected, and that infected fetuses tended to be clustered within the uterine horns, suggesting that virus is spread from fetus to fetus. Even though affected litters exhibited different degrees of gross pathology, the presence of an anatomical abnormality was not an identifier of an infected fetus. Analysis of virus replication in individual tissues identified the thymus as the principal site of PRRSV replication. The results show that PRRSV infection in the developing fetus follows a unique course and that PRRSV-induced alterations may be the result of the effect of PRRSV on maternal tissues. These factors need to be taken into consideration when diagnosing PRRSV infection as the cause for aborted and stillborn fetuses.

(Key Words: Porcine Reproductive and Respiratory Syndrome Virus, PRRS, Diagnostics, Fetal Infection.)

Introduction

At present, porcine reproductive and respiratory syndrome (PRRS) is responsible for incurring approximately $600 million a year in losses to producers. The reproductive form of PRRS is initiated by the infection of pregnant gilts/sows at about 90 days of gestation. Outcomes range from aborted and stillborn fetuses to piglets that are born live, but weak, with mortality sometimes approaching 100%. The impact of infection continues through the nursery and finishing stages and contributes to clinical respiratory disease development and mortality. Preventing reproductive PRRS is a key element in the reduction of losses that result from PRRS. The purpose of this study was to characterize sites of virus replication and sources of pathology in the PRRS-affected fetus.

Procedures

All animal procedures were reviewed and approved by the Kansas State University Animal Care and Use Committee. Four pregnant gilts, obtained from a closely monitored PRRSV-negative herd, were infected at 90 days of gestation with a sixth-passage isolate of SDSU-23983, a typical North American field

[1]Work supported by USDA-NRI competitive grant No. 03-35205-13704.

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

isolate. Three milliliters of virus, at a concentration of 10^4 $TCID_{50}$/ml, was divided into two doses and administered into each nare with a 3-ml syringe or was injected intramuscularly. Two mock-infected gilts served as a sources for normal fetuses. At between 108 and 111 days of gestation, gilts were sacrificed and both uterine horns were removed. Each fetus was individually removed. The location within the uterine horn and gross pathology, if present, were recorded, and fetuses were immediately necropsied. Amniotic fluid and blood were collected first. Tissues for virus isolation (VI) and histopathology included lung, heart, placenta, umbilical cord and the lymphoid-associated tissues, tonsil, thymus, mandibular lymph nodes, and inguinal lymph nodes. Virus isolation was performed by using standard techniques, and results were reported as the $\log_{10}$ of the inverse dilution of the last positive well per 1.0 ml of serum or gram of tissue. The PRRSV-specific antibody was measured in sera by using the HerdCheck® PRRS ELISA (IDEXX). Tissue samples were collected and immediately placed in 10% buffered formalin. Paraffin-embedded thin sections were mounted on slides processed for staining with hematoxylin and eosin (H and E). Immunohistochemical staining for PRRSV nucleocapsid antigen was performed by the diagnostic laboratory.

Results and Discussion

Clinical signs during infection of gilts were minimal. A total of 44 fetuses were recovered from the four infected gilts. Within one to two weeks after challenge, all infected gilts became VI-positive in serum, confirming the presence of an active infection. Three of the four infected gilts seroconverted, as indicated by a PRRSV ELISA S/P ratio greater than 0.39. Gross pathology was observed in all of the infected litters (Figure 1), including poorly developed or dead fetuses, abnormalities in amniotic fluid and placenta. A total of 24 fetuses were obtained from the two control gilts. All control fetuses seemed normal, except for two mummified fetuses, one less than 5 cm in length. Virus titers in serum and tissues and serology from infected fetuses and dams are presented in Figure 1 and Table 1. Ten of the 42 (24%) viable fetuses were positive for PRRSV by VI in serum. Infection was further confirmed by positive VI and immunohistochemistry (IHC) results from selected tissues. The number of infected fetuses in each litter ranged from no infected fetuses (dam No. 174) to 5 infected fetuses (dam No. 85). Fetuses that were VI-negative in serum were confirmed as PRRSV-negative by negative results for placenta, lung, lymph nodes, and thymus. Seven of the 10 infected fetuses showed some form of gross pathology. Ongoing virus replication in the fetus as the source of these changes is questionable, however, because non-infected fetuses from infected gilts exhibited some form of damage (Figure 1). For instance, the litter from dam No. 174, which was not infected, contained fetuses that were dead or exhibited some form of gross anatomical change. This observation suggests that maternal changes that result from infection are sources of fetal damage.

To identify the targets of virus replication in the fetus, a variety of tissues were assessed for the presence of virus and virus-infected cells. The results are presented in Table 1. Positive VI results were obtained from 6 of 10 lungs, 5 of 10 lymph nodes, 6 of 10 tonsils, and 9 of 10 thymuses. Within this group of tissues, the thymus contained the greatest quantity of virus. For instance, six thymuses yielded virus titers greater than 10^3/gram. The greatest numbers of antigen-positive slides were also found from thymus (Table 1). Considered together, these data identify the thymus as a primary site of virus replication in the PRRSV-infected fetus.

The results presented in this study describe several unique features of fetal PRRSV infection, which have important implications in the diagnosis of PRRSV as a cause of abortion.

First, not all fetuses are infected. Therefore, when performing VI or PCR to detect virus, several affected fetuses should be collected and/or samples should be pooled from several fetuses. Fetuses should be randomly selected and should include fetuses that seem "normal". Tissues chosen for VI or PCR analysis should include thymus. Thoracic fluid, a readily available source of serum and tissue fluid, is also a good source of virus and antibody.

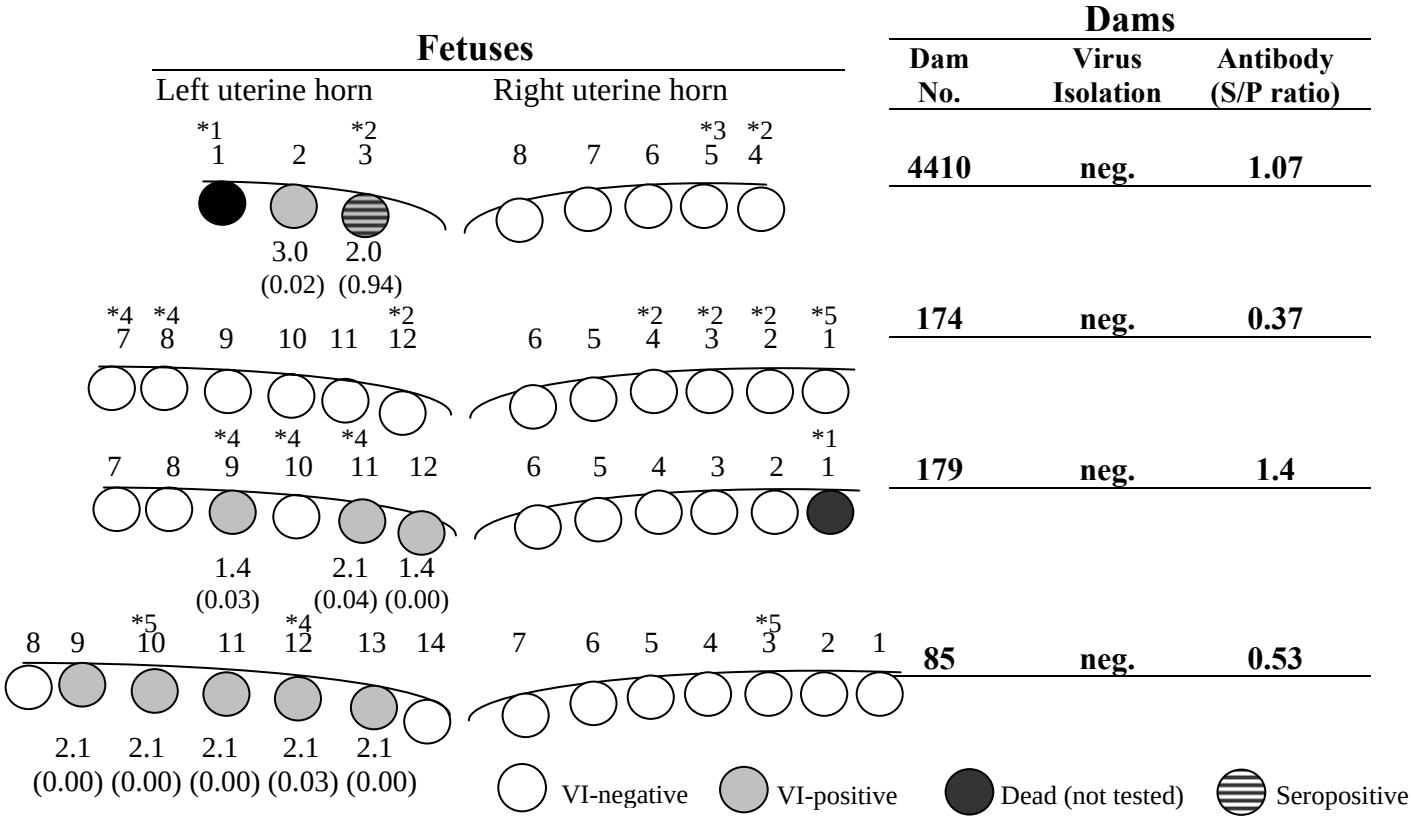


Figure 1. Location of Infected Fetuses Within the Uterine Horns. The identification number, VI, and serology data for each dam are on the right. Each circle represents the relative location of each fetus in the left and right uterine horns. The number above each fetus identifies the order of removal and the number used to identify fetuses in the text and in Table 1. Clear circles represent non-infected fetuses. The VI titer (the number below each shaded fetus), and serology (the numbers in parentheses) were performed on serum. Dead fetuses (black circles) were autolysed and not tested.

Gross Pathology Key

*1 Partly mummified
*2 Nonviable fetus or excessively small amounts of amniotic fluid
*3 Necrotic placenta
*4 Meconium- and/or blood-stained amniotic fluid
*5 Small fetus

Table 1. PRRS Virus Isolation and Immunohistochemistry (IHC) in Fetal Tissues[1]

Dam No.	4410		179			85				
Fetus No.	2	3	9	11	12	9	10	11	12	13
Placenta	3.6	n.m.[2]	1.0	1.6	1.9	2.4	n.m.	n.m.	2.7	1.3
Umbilical cord	n.d.[3]	1.4	1.3	2.2	1.6	2.2	2.0	1.2	1.1	1.9
Heart	1.7	1.8	2.5	2.6	1.4	2.8	n.m.	1.3	1.0	2.0
Lung	2.1	n.m.	1.0	n.m.	n.m.	0.8	n.m.	0.7	0.5	1.9
(IHC)	(-)[4]	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Lymph node[5]	3.6	n.m.	2.2	2.2	n.m.	3.0	n.m.	n.m.	1.3	n.m.
(IHC)	(-)	(-)	n.d.	(-)	n.d.	(-)	(-)	(+)	(-)	(+)
Spleen	2.3	n.m.	2.1	3.1	2.1	2.7	1.9	1.0	n.m.	1.6
(IHC)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(+)
Tonsil	1.3	1.4	1.2	1.2	2.2	3.2	n.m	n.m.	n.m.	n.m.
(IHC)	(-)	(-)	(n.d.)	(-)	(-)	(-)	(-).	(-)	(-)	(-)
Thymus	4.1	n.m.	1.6	2.3	3.6	1.6	3.5	3.5	2.2	4.2
(IHC)	(+)	(-)	(-)	(+)	(+)	(+)	(+)	(+)	(+)	(+)

[1]The VI results are presented as virus titer per gram of tissue.
[2]n.m.: Not measured. VI-negative at a dilution of 1:5.
[3]n.d.: Not determined.
[4]For lung, tonsil, and thymus tissues, the symbol in parenthesis indicates the presence (+) or absence (-) of cells positive for PRRSV antigen. The PRRSV antigen was detected by using immunohistochemistry as described in Figure 2. The results indicate the results obtained for a single thin section.
[5]Virus isolation was performed on mandibular lymph node. Immunohistochemistry data, in parentheses, include results for both mandibular and medial inguinal lymph nodes. A (+) indicates the presence of at least one PRRSV-positive cell.

FATTY ACID COMPOSITION OF THE PORCINE CONCEPTUS IN RESPONSE TO MATERNAL OMEGA-3 FATTY ACID SUPPLEMENTATION

A. B. Brazle, B. J. Johnson, E. C. Titgemeyer, S. K. Webel[1], and D. L. Davis

Summary

Marine and plant sources of omega-3 fatty acids have been evaluated for their effects on reproductive and other traits. Therefore we evaluated the effects of two sources of polyunsaturated fatty acids on the composition of the pig endometrium and conceptus. Treatments were Control, a corn-soybean meal diet; Flax, Control diet plus ground flax (3.75% of the diet); and PFA, Control plus a protected marine source of polyunsaturated omega-3 fatty acids (Fertilium®, 1.5% of diet). Supplements replaced equal parts of corn and soybean meal in the PFA and Flax diets.

Dietary treatments did not affect linoleic acid, linolenic, and arachidonic acid concentrations in conceptuses, but Flax increased ($P = 0.055$) eicosopentanoic acid (EPA) 78.8% and docosopentanoic acid (DPA) 32% ($P<0.05$) in the fetus. Gilts receiving PFA had 16% more ($P<0.006$) docosohexanoic acid (DHA) in their fetuses than fetuses in Controls had. Both Flax and PFA diets increased ($P<0.05$) DHA in the chorioallantois. In the endometrium, both EPA and DPA were increased ($P<0.02$) by the Flax diet, whereas the gilts receiving PFA had increased DHA ($P<0.0001$).

In summary, initiating fatty acid supplementation approximately 40 d before breeding with these omega-3 supplements affected conceptus and endometrial composition early in the fetal period of pregnancy. Further, plant and marine sources affected fatty acid composition differently. These differences may have implications for the physiological responses reported in the literature.

(Key Words: Embryo, Pigs, Omega-3 Fatty Acids.)

Introduction

Published research indicates that supplementing sow diets with a marine source of omega-3 fatty acids increases litter size and that adding salmon oil to the maternal diet increased both the omega-3 content of the brain and postnatal survival in pigs.

Omega-3 fatty acid supplements may be of either plant or marine origin. Plant sources contain significant amounts of linolenic acid, whereas marine sources contain appreciable eicosopentanoic acid (EPA) and docosohexanoic acid (DHA). Here we report the effects of ground flax seed and a marine source of polyunsaturated fatty acids (PUFA) on the fatty acid composition of the pig endometrium and conceptus.

[1]United Feeds, Sheriden, IN.

Procedures

At 170 days of age, twenty-four gilts (PIC C22 × 280; BW = 260 lb) were assigned randomly to dietary treatments. Gilts were injected with PG600® to induce puberty, and dietary treatments were initiated. Control gilts were fed a corn-soybean meal diet. Gilts assigned to Flax were fed the control diet containing 3.75% added ground flax, and the diet for PFA gilts contained a protected fatty acid (PFA) product (Fertilium®) containing 1.5% marine products to provide approximately equal amounts of EPA and DHA. Flax and PFA supplements replaced equal parts of corn and soybean meal from the control diet.

On d 20 of the experiment, a 14-d treatment of Matrix® was applied to synchronize estrus. Estrous detection was initiated 4 d after the last Matrix® treatment, and gilts were artificially inseminated the first and second days of estrus with semen from PIC 280 boars. Dietary treatments continued until d 40 to 43 of gestation, when gilts were slaughtered and reproductive tracts were removed for sample collection.

Gilts were penned in groups of 7 and fed *ad libitum*, except during Matrix treatment and until after artificial insemination, when gilts were penned individually in gestation stalls and fed 3.2 kg/day. After insemination, gilts returned to group pens and were fed *ad libitum*.

Samples were lyophilized and ground, and fatty acid composition was analyzed by using gas chromatography. Chromatography used a capillary column (SUPELCO SP™-2560, 0.25 mm × 100 m, film thickness 0.25 *u*m) equipped with a flame ionization detector. The carrier gas was helium, with a run time of sixty-five minutes. The column temperature was increased from 140 to 240ºC at 4ºC/minute and then held at 240ºC. The focus of the fatty acid analysis included linoleic acid, linolenic acid, arachidonic acid, EPA, docosopentanoic acid (DPA), and DHA.

Data are expressed as mg/g of lyophilized tissue and were analyzed by using the MIXED procedure of SAS, with gilt as the experimental unit.

Results and Discussion

Analysis of some dietary PUFA is in Table 1. Dietary treatments did not affect arachidonic or linoleic acid in the fetus, chorioallantois, or endometrial samples.

Table 1. Diet Fatty Acid Composition[a]

	Control	Flax	PFA
Linoleic	1.91	2.60	2.25
Linolenic	0.21	1.21	0.13
EPA	0.00	0.00	0.02
DHA	0.00	0.00	0.02

[a]Percentage of diet as fed.

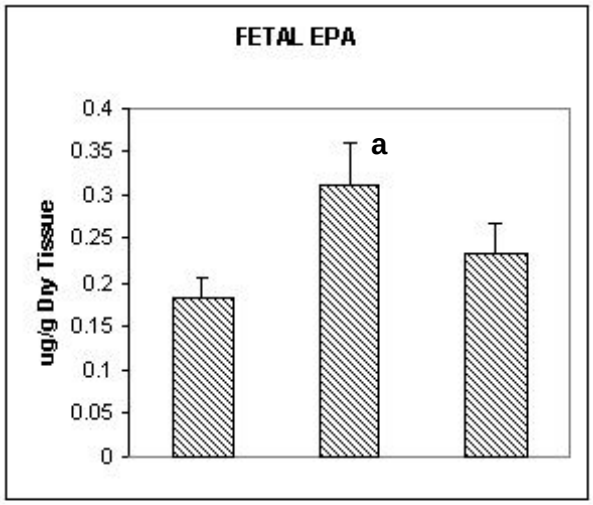
The Flax treatment increased concentrations of fetal EPA and DPA, compared with those of Control and PFA. Fetuses from gilts receiving the Flax treatment contained 78% more (P = 0.055) EPA/g and 32% more (P<0.05) DPA/g than did fetuses in Control gilts (Figure 1). Gilts fed PFA had fetuses with 16% more (P<0.01) DHA than Control fetuses had. It is of interest that fetuses in all treatments contained approximately seven times more DHA than EPA.

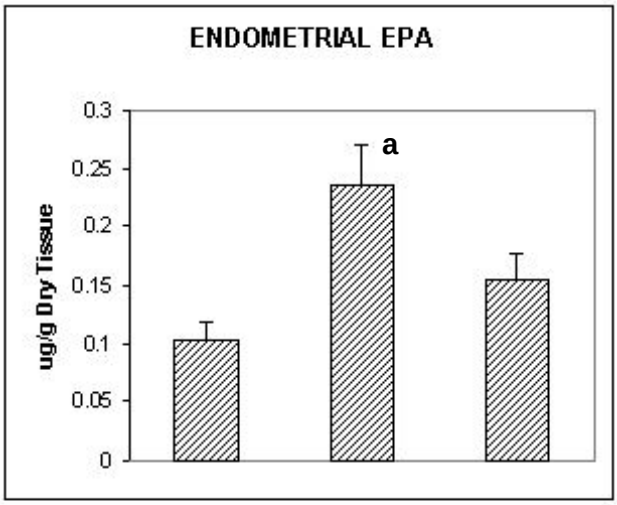
Dietary treatments did not affect EPA concentrations in the chorioallantois, but both Flax and PFA increased concentrations of DHA (P<0.05) in this placental tissue. Concentrations of DPA in the chorioallantois were unaffected by dietary treatments.

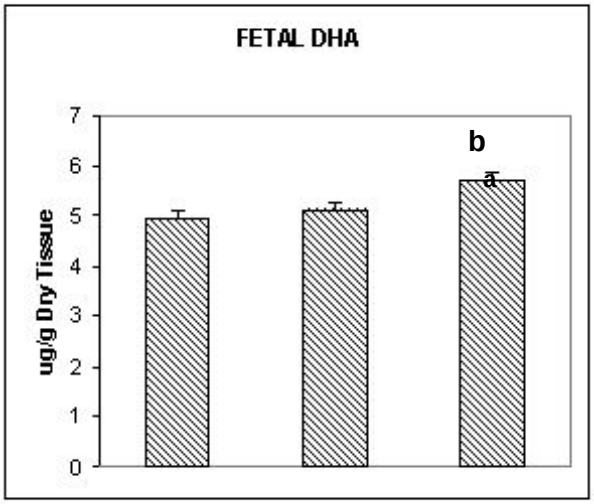
The fatty acid analysis of endometrial tissue revealed that the Flax treatment increased (P<0.05) concentrations of EPA and DPA and the PFA treatment increased concentrations of DHA in the endometrial tissue (P<0.01).

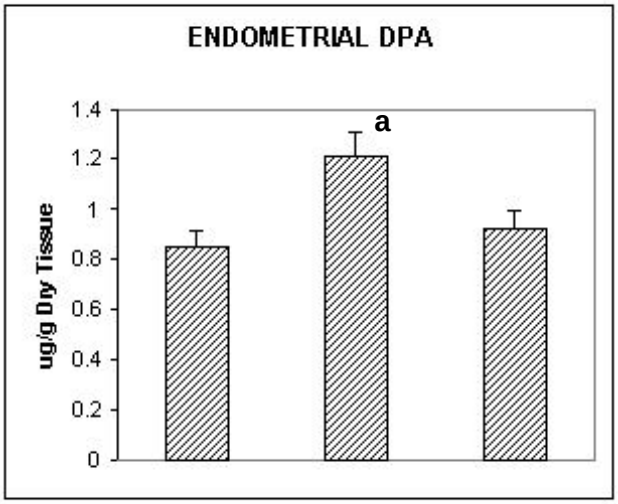
Supplemental flax, a rich source of α-linolenic acid, in the diet of pregnant gilts increased concentrations of EPA and DPA, but not DHA, in the fetus and endometrium. In comparision, supplementation with a marine source of EPA and DHA (PFA diet) increased DHA but not the other omega-3 fatty acids. This differential enrichment of tissues in the gravid uterus is consistent with literature reports describing other tissues in animals receiving similar supplements. It seems that α-linolenic acid is used as a substrate to synthesize EPA but is not effective for increasing DHA in the fetus and endometrium. Therefore, flax is not effective for increasing DHA in the pig fetus.

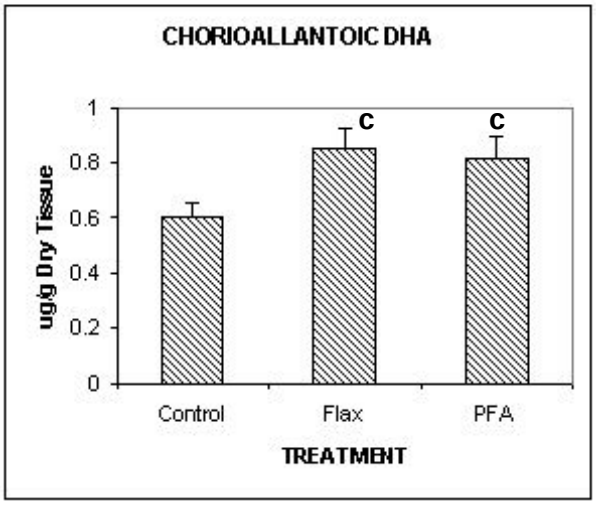
The chorioallantois provided an exceptional pattern in that both flax and marine oils resulted in higher concentrations of DHA. This observation may result from the physiological processes exchanging fatty acids between the mother, placenta, and fetuses. A better understanding of these processes in the pig may be useful for understanding prenatal fatty acid nutrition in this species.











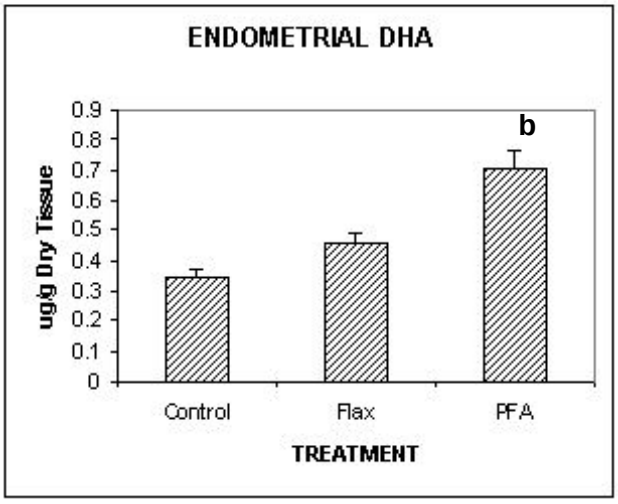


Figure 1. Fatty Acid Composition of the Porcine Conceptus. PFA = protected source of polyunsaturated fatty acids from marine sources. Superscripts indicate differences from other treatments, [a]P = 0.055; [b]P<0.05; [c]P<0.006.

Figure 2. Fatty Acid Composition of the Porcine Endometrium. Superscripts indicate differences from other treatments, [a]P<0.05; [b]P<0.0001.

INFLUENCE OF L-CARNITINE ON GROWTH AND PLASMA IGF-I FROM GILTS HARVESTED AT THREE GESTATION LENGTHS[1]

K. R. Brown, B. J. Johnson, R. D. Goodband, M. D. Tokach, S. S. Dritz[2], J. L. Nelssen, N. Z. Frantz, R. O. Gottlob, C. N. Groesbeck, C. W. Hastad, C. R. Neill, J. D. Schneider, M. G. Young, and J. C. Woodworth[3]

Summary

A total of 59 gilts were used to determine the effects of supplemental L-carnitine on gilt growth and maternal insulin-like growth factor-I (IGF-I). Experimental treatments were arranged in a 2 × 3 factorial with main effects of L-carnitine (0 or 50 ppm) and day of gestation (40, 55, or 70). All gilts received a constant feed allowance of 3.86 lb/day and a topdress containing either 0 or 88 mg of L-carnitine, starting on the first day of breeding. No differences (P>0.05) between treatments were observed for BW, estimated protein mass, or estimated fat mass at any gestation length. At d 70 of gestation, there was a numeric increase (P>0.10) in BW for the gilts fed L-carnitine, compared with those fed the control diet. At d 40 of gestation, gilts fed L-carnitine tended to have greater (P = 0.10) backfat, compared with the gilts fed the control diet; but no differences (P>0.05) were observed in backfat on d 0, 55, or 70 of gestation. In addition, no differences (P>0.05) were observed in maternal IGF-I between treatments at any gestation length. Total and free plasma L-carnitine concentrations were similar (P>0.10) at d 0 of gestation, but concentrations were higher (P<0.01) by d 40 of gestation in the gilts fed L-carnitine. These results show that supplemental L-carnitine numerically increases BW of gestating gilts. This data represents the first part of an ongoing study, with the rest of the data being reported in subsequent publications.

(Key Words: Backfat, Gestation, Gilts, L-carnitine, Pigs, Weight.)

Introduction

L-carnitine is a vitamin-like, water-soluble quaternary amine that is a derivative of the amino acids lysine and methionine. It is found in tissues such as the liver, kidney, brain, heart, and skeletal muscle, which can use fatty acids as an energy source. The primary role of L-carnitine is to facilitate transport of long-chain fatty acyl groups to the mitochondrial matrix for β-oxidation for cellular energy production. In addition, L-carnitine increases glucose disposal and carbohydrate oxidation rate, therefore playing a role in carbohydrate metabolism.

Research has demonstrated that supplementing sow's diets with L-carnitine during gestation improves reproductive performance.

[1]The authors thank Lonza, Inc., Allendale, New Jersey, for their financial support. Sincere appreciation is expressed to Cassie Benz, Leah Bond, Alexa Hayes, Drew Taylor, Meghan Tindle, and Amanda Wetzel for their assistance in data collection.

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

[3]Lonza, Inc., Allendale, NJ.

L-carnitine supplementation during gestation increased sow BW gain, and last-rib backfat, and in some studies has been shown to increase circulating IGF-I. In addition, supplemental L-carnitine in a sow's diet increased pig and litter weight at birth, reduced the number of stillborn pigs, and increased litter size.

To our knowledge, two research groups have studied the effect of L-carnitine supplementation on performance parameters in gilts. The addition of dietary L-carnitine to gestation diets has not shown consistent performance on first-parity reproductive performance. Therefore, our objective in this study was to determine the effects of supplementing with L-carnitine through the developmental stages of gestation. We examined gilt weight, backfat, circulating IGF-I, and free and total L-carnitine at d 0, 40, 55, and 70 of gestation.

This experiment is part of a large, comprehensive study designed to evaluate the effects of L-carnitine on gilt reproductive performance, the IGF system in maternal tissues, fetal traits such as IGF gene expression in fetal myoblasts, and fetal muscle cell proliferation and differentiation.

Procedures

Animals and Feeding Protocol. All animal procedures used in this study were reviewed and approved by the Kansas State University Animal Care and Use Committee. Fifty-nine terminal gilts (PIC, Franklin, KY; L327 × 1050; BW = 303.6 lb) were artificially inseminated (PIC; MQ 280) 12, 24, and 36 h after the onset of the second observed estrus. Gilts were housed in individual gestation crates (7 ft × 22 in) in an environmentally controlled gestation barn at the Kansas State University Swine Teaching and Research Center. Gilts were allowed *ad libitum* access to water, and were randomly allotted to one of two dietary treatments and one of three harvesting dates (d 40, 55, or 70 of gestation) on the basis of weight at breeding. All gilts were fed a corn-soybean meal gestation diet (Table 1) once daily (3.86 lb/day), and received a 50 g top-dress containing either none (control, n = 30) or 88 mg (equivalent to approximately 50 ppm on an as-fed basis) of L-carnitine (Carniking 10 (10% of L-carnitine), n = 29; Lonza, Inc., Allendale, NJ) from d 1 until d 39, 54, or 69 of gestation. Last-rib backfat and weight were determined at breeding and at d 39, 54, and 69 of gestation. Blood was collected by veni-puncture 6 hr after feeding, for determination of circulating IGF-I and free and total L-carnitine, at d 0, 39, 54, and 69 of gestation.

Table 1. Diet Composition Fed During Gestation[a]

Item	Gestation Diet
Ingredient, %	
Corn	81.22
Soybean meal (46.5% CP)	14.55
Monocalcium P (21% P)	2.03
Limestone	1.05
Salt	0.50
Vitamin premix	0.25
Trace mineral premix	0.15
Sow add pack	0.25
Total	100.00
Calculated analysis	
Lysine, %	0.65
ME, kcal/lb	1,483
Protein, %	13.7
Ca, %	0.85
P, %	0.75
Available P, %	0.48

[a]Gestation feeding of 3.86 lb/d, with or without a top-dress providing 88 mg/d (equivalent to 50 ppm on an as-fed basis) added L-carnitine.

Statistical Analysis. Backfat, weight, and maternal blood concentrations of L-carnitine and IGF-I were compared by using the

MIXED procedure of SAS. Data were analyzed as repeated measures to include only the gilts harvested at d 70 of gestation (control, n = 10; L-carnitine, n = 10). The model included treatment as the fixed effect and day of sampling as the repeated measure. The Kenward-Roger adjustment was used to calculate the degrees of freedom. Significance was declared at $P<0.05$ unless otherwise noted.

Results and Discussion

No differences ($P>0.05$) between treatments were observed for BW, estimated protein mass, and estimated fat mass at any gestation length, although day of sampling was significant for these response criteria (Table 2; $P<0.0001$). At d 70 of gestation, there was a numerical increase ($P = 0.43$) in BW for the gilts fed L-carnitine, compared with that of gilts fed the control diet (L-carnitine = 375.5 lb vs. control = 366.6 lb). At d 40 of gestation, gilts fed L-carnitine tended to have greater ($P = 0.10$) backfat than did the gilts fed the control diet (L-carnitine = 17.9 mm vs. control = 16.3 mm), but no differences ($P>0.05$) were observed in backfat on day 0, 55, or 70 of gestation between dietary treatments. Backfat increased for gilts fed dietary treatments from d 0 to 55 gestation, but then decreased from d 55 to d 70 of gestation.

Maternal IGF-I concentrations decreased ($P<0.0001$) from d 0 to 70 of gestation for the gilts fed supplemental L-carnitine and those fed the control diet (Figure 1). No differences ($P>0.05$) were observed for maternal IGF-I collected at d 0, 40, 55, or 70 of gestation between the two treatments. No differences ($P>0.05$) were observed in total and free L-carnitine between the gilts fed L-carnitine and those fed the control diet at d 0 of gestation. Plasma total and free L-carnitine increased ($P<0.0001$) on d 40, 55, and 70 of gestation for gilts fed the L-carnitine top-dress (Figures 2 and 3).

Results of this study show that supplemental L-carnitine numerically increased gilt BW at d 70 of gestation, without a significant change in backfat. The underlying biochemical mechanisms are not clear, but the same trends have been observed in previous studies. One function of L-carnitine is to transport fatty acids to the inner mitochondrial membrane for β-oxidation, perhaps sparing more amino acids for protein deposition or providing additional energy to be used for intrauterine nutrient supply.

Previous research has shown that providing supplemental L-carnitine to sows increased circulating IGF-I. Pigs from the litters of these sows were heavier at birth. The role of IGF-I in normal growth and development has been well documented, and it plays an important role in muscle cell proliferation. Thus, the elevated levels of IGF-I may have improved muscling in these pigs. In contrast, other researchers have found no changes in circulating IGF-I in sows fed L-carnitine, when determined at d 55 of gestation, even though the litters from sows fed the L-carnitine were heavier. These researchers suggested that the heavier litter weights from sows fed L-carnitine were not due to increased maternal IGF-I. The results of the current study suggest that circulating IGF-I is similar for gilts fed supplemental L-carnitine and gilts fed diets without supplemental L-carnitine.

In conclusion, providing supplemental L-carnitine to gestating gilts increased maternal circulating total and free L-carnitine at each gestation day. This is beneficial because L-carnitine plays a role in protein synthesis, glucose homeostasis, and β-oxidation. At d 70 of gestation, L-carnitine supplementation resulted in numerically increased gilt BW. As gestation progressed, IGF-I decreased, but no treatment differences were observed in maternal IGF-I at any gestation length. Therefore,

any treatment differences in reproductive parameters may not be due to maternal IGF-I.

This experiment is one part of a large, comprehensive study designed to evaluate the effects of L-carnitine on litter characteristics such as weight, fetus number, and the IGF system. Also, the IGF system in tissues from the gilt placenta and the endometrium and myometrium from the gilt uterus will be examined to determine the effects of supplemental L-carnitine. Last, we will examine the effects of L-carnitine on IGF gene expression in fetal myoblasts and its effects on fetal muscle cell proliferation and differentiation.

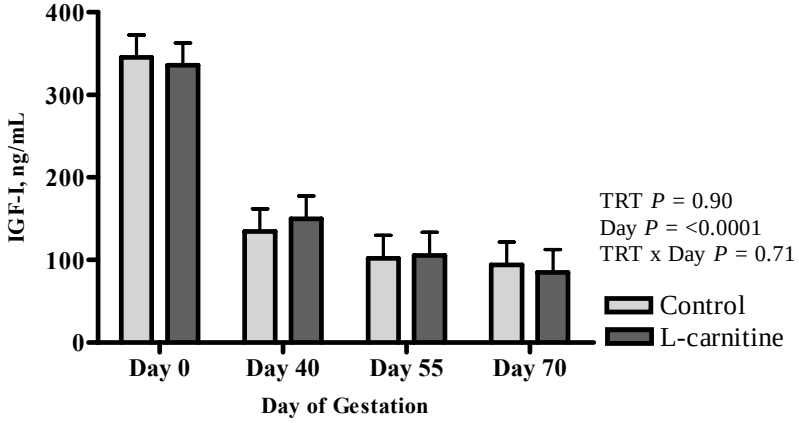


Figure 1. The Influence of Feeding Gilts L-carnitine on Serum IGF-I Concentrations.

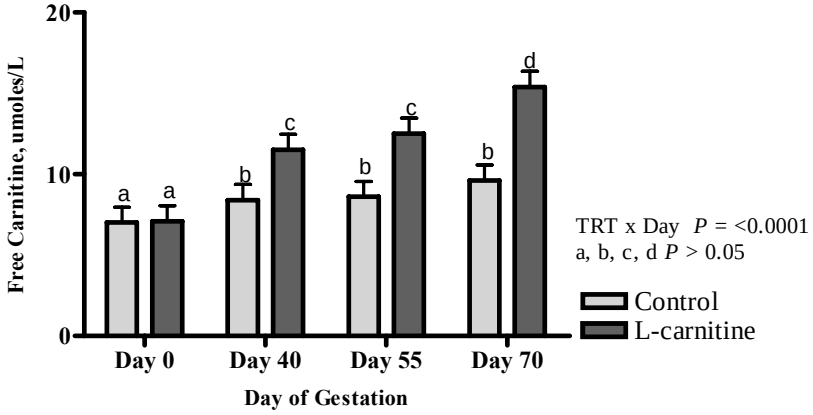


Figure 2. The Influence of Feeding L-carnitine to Gilts on Circulating Free Carnitine.

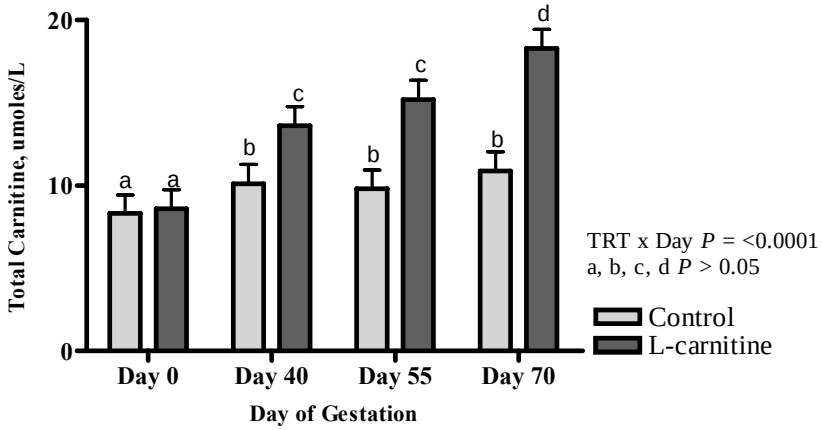


Figure 3. The Influence of Feeding Gilts L-carnitine on Circulating Total Carnitine.

Table 2. Effects of L-carnitine on Gilt Growth Characteristics[a]

Item	Control	L-carnitine	Probability, $P <$ Treatment	SE
No. of Gilts	10	10		
Weight, lb				
d 0	300.9	298.8	0.86	11.20
d 40	331.8	340.0	0.47	11.20
d 55	349.4	358.2	0.44	11.20
d 70	366.6	375.5	0.43	11.20
Estimated protein mass, lb[b]				
d 0	50.8	50.3	0.82	2.00
d 40	55.9	56.8	0.66	2.00
d 55	58.9	60.3	0.50	2.00
d 70	62.2	63.9	0.40	2.00
Backfat, mm				
d 0	15.0	15.2	0.83	0.95
d 40	16.3	17.9	0.10	0.95
d 55	16.7	17.2	0.60	0.95
d 70	15.9	15.4	0.60	0.95
Estimated fat mass, lb[c]				
d 0	60.2	60.2	0.99	2.86
d 40	68.7	72.9	0.16	2.86
d 55	73.2	76.0	0.34	2.86
d 70	75.9	77.4	0.61	2.86

	Trt	Day of Sample	Trt × Day of Sample
Weight, lb	0.58	<0.0001	0.11
Estimated protein mass, lb	0.64	<0.0001	0.20
Backfat, mm	0.30	0.0023	0.35
Estimated fat mass, lb	0.44	<0.0001	0.10

[a]d 0 to 70.
[b]Prediction equation from Dourmad et al. (1997), 2.28 + 0.178 (liveweight, lb) – 0.333 × (backfat, mm).
[c]Prediction equation from Dourmad et al. (1997), -26.40 + 0.221 × (liveweight, lb) + 1.331 × (backfat, mm).

INFLUENCE OF L-CARNITINE ON LITTER CHARACTERISTICS FROM GILTS HARVESTED AT DAY 40, 55, AND 70 OF GESTATION[1]

K. R. Brown, B. J. Johnson, R. D. Goodband, M. D. Tokach, S. S. Dritz[2], J. L. Nelssen, E. J. Minton, A. E. Brazle, T. E. Burkey, C. N. Groesbeck, C. R. Neill, J. D. Schneider, and J. C. Woodworth[3]

Summary

A total of 59 gilts were used to determine the effects of supplemental L-carnitine on reproductive performance. Experimental treatments were arranged in a 2 × 3 factorial with main effects of L-carnitine (0 or 50 ppm) and day of gestation (40, 55, or 70). All gilts received a constant feed allowance of 3.86 lb/day and a top-dress containing either 0 or 88 mg of L-carnitine, starting on the first day of breeding and continuing until the day of harvest. Total litter size, total litter weight, and crown-to-rump length of fetuses were not different (P>0.10) between treatments at any gestation length. By d 70 of gestation, average fetus weight was heavier (P = 0.06) for fetuses from gilts fed L-carnitine, compared with fetuses from gilts fed the control diet. In addition, at d 70, fetal insulin-like growth factor-II (IGF-II) concentrations were lower (P = 0.09) for fetuses from gilts fed L-carnitine than for fetuses from gilts fed the control diet. Feeding L-carnitine may have decreased fetal IGF-II, therefore increasing cell proliferation and delaying cell differentiation. These results show that providing supplemental L-carnitine to gestating gilts has beneficial effects on average fetal weight, possibly observed because of its ability to reduce fetal IGF-II concentrations.

(Key Words: Fetus, Gestation, Gilts, IGF-II, L-carnitine.)

Introduction

Research has shown that supplementing sow's diets with L-carnitine during gestation improves performance criteria. Providing supplemental L-carnitine in a sow's diet has been shown to increase pig and litter weights at birth, reduce the number of stillborn pigs, and increase litter size. Research reported in a separate article (page 12) showed that supplementing L-carnitine to gestating gilts numerically increased weight gain at d 70 of gestation, but no differences were observed for maternal IGF-I. No data currently exist for the effects of L-carnitine on fetal IGF-II values.

The addition of dietary L-carnitine to gestation diets has resulted in inconsistent data on first-parity reproductive performance. Therefore, our objective of this study was to deter-

[1]The authors thank Lonza, Inc., Allendale, New Jersey, for their financial support. Sincere appreciation is expressed to Cassie Benz, Leah Bond, Alexa Hayes, Drew Taylor, Meghan Tindle, and Amanda Wetzel for their assistance in data collection

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

[3]Lonza, Inc., Allendale, NJ.

mine the effects of supplementing with L-carnitine through the developmental stages of gestation. We examined total litter weight, average fetal weight, total fetus number, fetus number in the left and right uterine horn, fetal crown-to-rump length, fetal IGF-II, and gilt corpora lutea on each ovary at three gestation points.

Procedures

Animals and Feeding Protocol. All animal procedures used in this study were reviewed and approved by the Kansas State University Animal Care and Use Committee. Fifty-nine terminal gilts (PIC, Franklin, KY; L327 × 1050; BW = 303.6 lb) were artificially inseminated (PIC; MQ 280) 12, 24, and 36 h after the onset of the second observed estrus. Gilts were housed in individual gestation crates (7 ft × 22 in) and allowed *ad libitum* access to water in an environmentally controlled gestation barn at the Kansas State University Swine Teaching and Research Center. Gilts were randomly allotted to one of two dietary treatments and one of three harvesting dates (d 40, 55, or 70 of gestation) on the basis of weight at breeding. All gilts were fed a corn-soybean meal-based gestation diet (Table 1) once daily (3.86 lb/d), and received a 50-g top-dress containing either 0 (control, n = 30) or 88 mg (equivalent to approximately 50 ppm on an as-fed basis) of L-carnitine (Carniking 10 (10% of L-carnitine), n = 29; Lonza Group, Inc., Allendale, NJ) from d 1 to d 39, 54, or 69 of gestation.

Harvesting Protocol and Collection of Samples. Gilts were harvested at d 40, 55, or 70 of gestation. Fifteen hours before harvest, gilts were transported from the Kansas State University Swine Teaching and Research Center to the Kansas State University Meat Laboratory. Gilts were allowed *ad libitum* access to water, and collections were performed 24 h after the last feeding. Gilts were harvested by electrical stunning, followed by exsanguination. A mid-lateral incision was made to gain access to the abdominal cavity, and the uterus was removed. Once the uterus was removed, the number of fetuses was determined on both sides, and fetuses were immediately removed under aseptic conditions. The fetuses were transported to the Kansas State University Growth Laboratory for additional processing. The number of corpus lutea on each ovary was determined.

Table 1. Diet Composition Fed During Gestation[a]

Item	Gestation Diet
Ingredient, %	
Corn	81.22
Soybean meal (46.5% CP)	14.55
Monocalcium P (21% P)	2.03
Limestone	1.05
Salt	0.50
Vitamin premix	0.25
Trace mineral premix	0.15
Sow add pack	0.25
	100.00
Calculated analysis	
Lysine, %	0.65
ME, kcal/lb	1,483
Protein, %	13.7
Ca, %	0.85
P, %	0.75
Available P, %	0.48

[a]Gestation feeding of 3.86 lb/d, with or without a top-dress providing 88 mg/d (equivalent to approximately 50 ppm on an as-fed basis) added L-carnitine.

Fetal Blood Collection, Weights, and Lengths. Individual fetus weight and crown-

to-rump length were determined. Total litter weight was calculated as the sum of the individual fetus weights per litter. Fetal blood was collected from the heart of each fetus, and pooled with the other fetuses in the litter for determination of fetal IGF-II.

Statistical Analysis. Fetal weights, lengths, and circulating IGF-II, and gilt corpora lutea, were analyzed as a 2 × 3 factorial design with the MIXED procedure of SAS. Fixed effects included treatment, day of harvest, and their interaction. Kenward-Roger adjustment was used for the degrees of freedom. Proc Mixed of SAS was used to determine the slopes of average fetus weight vs. fetus number per litter at d 40, 55, and 70 of gestation. Fixed effects included treatment × day of harvest, and treatment × day of harvest × fetus number. Estimate statements were used to determine slope differences of average fetus weight vs. number of fetuses per litter. Regression was used to determine if the slopes were different from zero. The fixed effect included number of fetuses, separated by treatment and day of harvest. The Fisher's Exact method was used to determine p-values of a chi-square statistic between differences in the number of litters having detectable IGF-II for control gilts and those fed L-carnitine. The significance was declared at $P<0.05$ unless otherwise noted.

Results and Discussion

Total litter size and total litter weight were not different ($P>0.05$) at d 40, 55, or 70 of gestation for the gilts fed L-carnitine and those fed the control diet. In addition, no differences ($P>0.05$) were observed between treatments for number of fetuses in the right uterine or left uterine horn and fetal crown-to-rump length at the three gestation lengths. No differences ($P>0.05$) were observed in total, right, or left corpus lutea at d 40, 55, and 70 gestation for the gilts fed L-carnitine and those fed the control diet. The number of corpora lutea located on the left ovary decreased ($P = 0.07$) as gestation length increased. As gestation length increased, total litter weight, average fetal weight, and fetal crown-to-rump length increased ($P<0.05$), but total number of fetuses and number of fetuses in the right and left uterine horns decreased ($P<0.05$). At d 70 of gestation, fetuses from the gilts fed L-carnitine tended to be heavier ($P = 0.06$) than fetuses from the control gilts (Table 2; 236.6 g vs. 217.7 g, respectively). Fetal IGF-II concentrations tended to be lower ($P = 0.09$) at d 70 for the fetuses from the gilts fed L-carnitine than for the fetuses from the gilts fed the control diet (17.9 ng/mL vs. 22.9 ng/mL). In addition, fetal IGF-II was undetectable for ten of the twenty L-carnitine litters analyzed, and only one control litter had undetectable IGF-II (data not shown; $P = 0.0033$).

Average fetal weight was positively correlated ($R^2 = 0.68$) with number of fetuses for the control pigs at d 40 of gestation, whereas L-carnitine litters showed a weak positive correlation. Therefore, at d 40 of gestation, there was a strong correlation that the more fetuses per litter in the control sows, the heavier the average fetus was for those litters. At d 55 of gestation, there was no correlation (L-carnitine, $R^2 = 0.0001$; control $R^2 = 0.01$) between average fetus weight and number of fetuses per litter for the two treatments. At d 70 of gestation, negative correlations were observed (Figure 1). As number of fetuses per litter increased, the average fetus weight decreased. On d 70, correlations among average fetus weight and number of fetuses per litter were weak (L-carnitine, $R^2 = 0.17$; control $R^2 = 0.08$). Through gestation, correlations went from positive to negative. The correlations were different ($P = 0.06$) between d 40 and d 70 of gestation for the L-carnitine litters. The slopes of the litters from the gilts fed the control diet followed the same trend, but differences were not significant. In addition, the slopes at d 40, 55, and 70 were not different

between the two treatments (P>0.05; Figure 1A, B, and C).

In the current study, pigs from gilts fed supplemental L-carnitine had heavier average fetal weights at d 70 of gestation than the pigs from gilts fed the control diet, but no changes were observed in maternal IGF-I (see separate report, page 12). The role of maternal IGF-I in fetal muscle growth has been unclear. Unequivocal findings on the effects of maternal IGF-I from L-carnitine supplementation have shown that L-carnitine has increased and decreased maternal IGF-I concentrations. Researchers have found that supplemental L-carnitine increased maternal IGF-I and litter weights, concluding that maternal IGF-I played a role in increased fetal muscle proliferation. In contrast, other researchers have found no increase in circulating IGF-I in sows fed L-carnitine and having heavier litters. This suggests that the heavier litter weights from sows fed L-carnitine were not due to maternal IGF-I. The results of the current study suggest that circulating IGF-I is similar for gilts fed supplemental L-carnitine and gilts fed diets without supplemental L-carnitine. Therefore, the role of maternal IGF-I on impacting fetal muscle growth is unclear.

In this study, we found half of the litters from gilts fed L-carnitine had no detectable fetal IGF-II, and fetal IGF-II concentrations were lower at d 70 of gestation from the gilts fed L-carnitine. In muscle cells, IGF-I promotes muscle proliferation; IGF-II can promote muscle differentiation. The average fetus weight from the gilts fed L-carnitine was 18.9 g heavier than the average fetus weight from the gilts fed the control diet at d 70 of gestation. Feeding L-carnitine may have increased fetal IGF-I and decreased fetal IGF-II. Therefore, feeding L-carnitine may have increased cell proliferation, producing heavier fetuses, and caused a delay in muscle cell differentiation late in gestation.

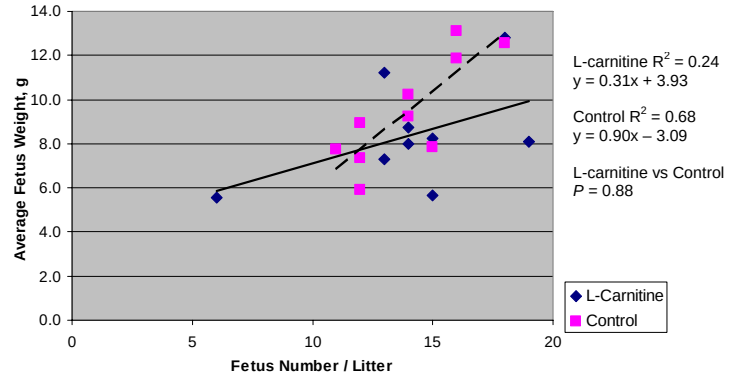
Previous research has reported that increased uterine crowding in prolific species in early gestation has negative consequences on muscle-fiber development, specifically secondary muscle-fiber development. At d 40 of gestation, we observed positive correlations for number of fetuses per litter vs. average fetus weight. Slopes were different for the L-carnitine litters at d 40 and 70 (P = 0.06), which suggests a biological change between d 40 and 70 of gestation. This may have contributed to the observed increase in fetal weight in the fetuses at d 70 from the gilts receiving supplemental L-carnitine. Fetal IGF-II concentrations were lower for the L-carnitine fetuses at d 55 and 70 of gestation. L-carnitine may be reducing fetal IGF-II concentrations and inhibiting uterine crowding early in gestation, therefore having beneficial consequences for muscle-fiber development.

Providing supplemental L-carnitine to gestating gilts increased gilt BW and average fetus weight at d 70 of gestation, and may have reduced uterine crowding at d 40 of gestation. L-carnitine may be inhibiting differentiation and positively regulating proliferation of myogenic cells in the fetus through gestation, therefore increasing fetal weight. Additional knowledge about developmental regulation of the growth-factor system in cultured myogenic cells from gilts fed L-carnitine will aid in our understanding of increased weight observed in fetuses from gilts fed L-carnitine. Therefore, our future research will focus on growth-factor expression from cultured porcine embryonic myoblasts at d 40, 55, and 70 of gestation. Results from the rest of this study will be published in a future report.

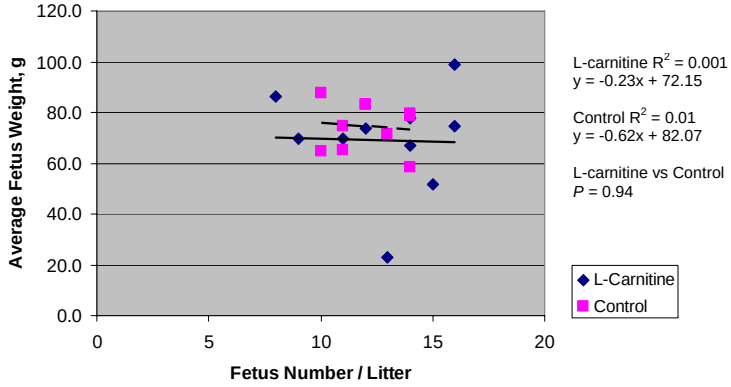
Table 2. Effects of L-carnitine on Litter and Ovary Characteristics

							Probability, $P <$					
	Control			L-carnitine			Control vs. L-carnitine			Trt SE		
Item	d 40	d 55	d 70	d 40	d 55	d 70	d 40	d 55	d 70	d 40	d 55	d 70
No. of Gilts	10	10	10	9	10	10						
Litter												
Total weight, g	136.7	901.0	2484.5	122.4	883.9	2657.1	0.94	0.93	0.35	188.20	183.18	183.18
Average fetal weight, g	9.5	74.6	217.7	8.4	69.2	236.6	0.92	0.59	0.06	10.30	9.95	9.95
Total fetus no.	14.0	12.1	11.5	14.1	12.8	11.4	0.93	0.56	0.93	1.23	1.20	1.20
Fetus no. right horn	7.4	5.7	5.8	6.9	6.1	6.2	0.51	0.60	0.60	0.77	0.75	0.75
Fetus no. left horn	6.6	6.3	5.7	7.1	6.7	5.1	0.49	0.63	0.45	0.76	0.74	0.74
Crown to rump, cm	5.3	12.0	16.8	5.2	11.6	16.8	0.81	0.32	0.91	0.33	0.32	0.32
IGF-II,	*	16.3	22.9	*	14.5	17.6	*	0.62	0.09	*	3.54	3.04
Corpora lutea												
Total	17.2	16.9	15.7	18.1	17.1	16.4	0.50	0.84	0.61	1.30	1.26	1.26
Right ovary	9.4	9.5	9.6	9.4	8.7	9.5	0.99	0.53	0.93	1.30	1.26	1.26
Left ovary	7.8	7.6	6.1	8.8	8.4	6.9	0.41	0.49	0.49	1.18	1.15	1.15

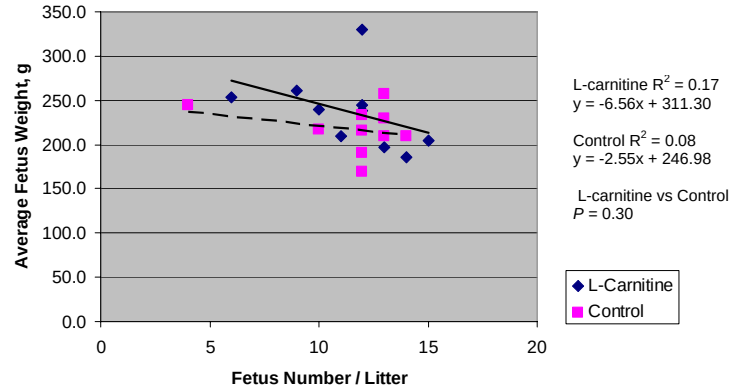
	Overall		
Litter	Trt	Day	Trt × Day
Total weight, g	0.66	<0.001	0.71
Average fetal weight, g	0.48	<0.001	0.19
Total fetus no.	0.74	0.01	0.89
Fetus no. right horn	0.83	0.05	0.63
Fetus no. left horn	0.80	0.02	0.54
Crown to rump, cm	0.44	<0.0001	0.80
IGF-II	0.14	0.05	0.45
Corpora lutea			
Total	0.42	0.20	0.94
Right ovary	0.68	0.88	0.90
Left ovary	0.20	0.07	0.99



A



B



C

Figure 1. Relationship Between the Number of Fetuses per Gilt and Average Fetus Weight at Day 40 (A), 55 (B), and 70 (C) Gestation.

DETERMINING THE THREONINE REQUIREMENT OF THE LACTATING SOW[1]

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

Summary

A total of 182 lactating sows were used in a study to determine the threonine requirement, and the relative difference in resulting performance of lactation diets with high concentrations of crystalline amino acids, compared with a conventional corn-soybean meal diet. All experimental diets were based on corn-soybean meal and formulated to contain 0.88% true ileal digestible (TID) lysine (1.00 and 0.97% total lysine for the control treatment and crystalline amino acid treatments, respectively). The control treatment was a conventional corn-soybean meal diet with no added crystalline amino acids. The other five experimental diets contained 0.37% L-lysine HCl, with other amino acids added to ensure that threonine was first limiting. The TID threonine contents in these diets were formulated to 0.44, 0.50, 0.57, 0.64, and 0.70%. Sows were farrowed in seven farrowing groups and were randomly allotted to the dietary treatments on the basis of parity. Over the entire lactation period, sows fed the diets containing crystalline amino acids consumed more (P<0.04) feed than did the sows fed the control corn-soybean meal diet. The sows fed the control diet also lost numerically (P>0.10) more weight over the lactation period. Sows fed the control diet had higher (P<0.01) PUN values at day 18 of lactation than did sows fed diets with added crystalline amino acids. There was no effect (P>0.10) on litter weaning weight with increasing dietary threonine. The numeric changes in PUN, litter weight gain, and feed intake suggest that the TID threonine requirement was 0.50%, which calculated to a threonine-to-lysine ratio of 57%. But the greatest implication of this study was that the use of crystalline amino acids as a replacement for soybean meal in lactation diets resulted in increased feed intake and decreased sow weight loss.

(Key Words: Crystalline Amino Acids, Lactation, Sows, Threonine.)

Introduction

To maximize milk production, nutritionists need to accurately formulate diets to contain the required amounts of amino acids for the sow. This can be challenging because overall production can dramatically affect the sow's amino acid needs. If diets are limiting in certain amino acids or energy, the sow will mobilize body protein or fat to meet their needs for milk production. Crystalline amino acids have become more readily and economically avail-

[1]The authors thank Ajinomoto Heartland LLC, for providing the crystalline amino acids used in this study.

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

able in recent years. Increased use of crystalline amino acids increases the importance of understanding the requirements for amino acids other than lysine in sow lactation diets to prevent an imbalance of essential amino acids.

Therefore, our objective in this study was to determine the threonine requirement of the high-producing lactating sow by using diets that contained high concentrations of crystalline amino acids. We also wanted to compare the performance of sows fed the diets containing large amounts of crystalline amino acids with that of sows fed a control diet based on corn-soybean meal.

Procedures

This study was conducted in the Kansas State University Swine Teaching and Research Center farrowing facilities. One hundred and eighty-two sows were blocked by parity and allotted to one of six diets. The sows used in this study were PIC Line 1050 and were farrowed in seven groups, with approximately 29 sows per group. Sows were randomly assigned to treatments, balanced by parity when entering the farrowing house on day 110 of gestation. During lactation, sows were provided *ad libitum* access to feed and water, and feed disappearance was recorded. All sows were fed either a diet based on corn-soybean meal or a diet containing large amounts of crystalline amino acids, formulated to 0.44, 0.50, 0.57, 0.64, or 0.70% TID threonine (Table 1). All diets were formulated to contain 0.88% TID lysine and 1,536 kcal of ME per lb.

All sows were weighed after farrowing and again at weaning to calculate weight change during lactation. Backfat was measured upon entering the farrowing house on d 110 of gestation and on d 18 of lactation to determine change in backfat during lactation. Blood samples were obtained by venipuncture on d 18 of lactation from each sow after 3 h of feed withdrawal, and samples were analyzed for plasma urea N (PUN). Cross-fostering occurred before d 2 to standardize all litters with approximately 11 pigs. Pigs were weighed individually at birth, after fostering on d 2, and again at weaning. Any pigs removed from the trial were recorded, along with their date of removal and weight. Data were analyzed according to the MIXED procedure of SAS.

Results and Discussion

Increasing TID threonine had no effect on ADFI over the lactation period, but sows fed the diets containing crystalline amino acids consumed more feed ($P < 0.05$; Table 2) than did sows fed the corn-soybean meal control diet. Sow body weight loss during lactation was not affected by lactation treatment, although sows fed the conventional corn-soybean meal diet lost numerically more weight than did sows fed the diets containing large amounts of crystalline amino acids. There was no difference for initial backfat and final backfat measured on d 18 of lactation among treatments, but sows fed the diet containing 0.50% TID threonine lost more ($P<0.10$) backfat than did sows fed the diet containing 0.57% TID threonine. Increasing dietary threonine did not affect PUN when blood was sampled on day 18 of lactation, but sows fed the conventional corn-soybean meal diet had higher ($P<0.01$) PUN than did sows fed the diets with large amounts of crystalline amino acids. Threonine concentration did not affect total litter weight at weaning ($P>0.10$; Table 3), but litter weaning weights were numerically maximized at 0.50% TID threonine. Sows suckled an average of 10.5 piglets during lactation, and mortality rate of piglets ranged from 5.94 to 9.15%.

Regression analysis of litter weaning weights indicated that the threonine require-

ment was approximately 0.50% for sows in this study. To support the 149 lb litter weaning weight and 114 lb of litter weight gain from d 2 to 21 without losing body protein, sows would have had to consume more than 58 g of TID lysine per day. With ADFI of approximately 12 lb/day, sows on the diets with large amounts of crystalline amino acids actually consumed approximately 48 g of TID lysine per day. Thus, sows consumed less than their lysine requirement, allowing calculation of a threonine:lysine ratio. When 0.50% TID threonine and 0.88% TID lysine were used, the threonine:lysine ratio calculated to 57%. This ratio is similar to the ratio of approximately 58% calculated from estimates of the National Research Council.

Finally, we observed that the litter performance of the sows fed the crystalline amino acid diets was not different from that of the sows fed the conventional corn-soybean meal diet. This could be a very useful tool for producers who want to decrease the nitrogen excreted into manure storage by sows without adversely affecting piglet growth during lactation. It also may offer a means of increasing feed intake, compared with diets that contain large amounts of soybean meal.

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

Item	Control[b]	Crystalline Amino Acids[c]
Corn	65.88	76.20
Soybean meal (46.5% CP)	27.47	16.00
Soybean oil	2.50	2.50
Monocalcium P (21% P, 18% C)	1.95	2.00
Limestone	1.05	1.00
Salt	0.50	0.50
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Sow add pack	0.25	0.25
L-valine	---	0.31
L-isoleucine	---	0.04
L-tryptophan	---	0.05
L-threonine	---	---
L-lysine HCl	---	0.37
DL-methionine	---	0.10
Sand	---	0.30
Total	100.00	100.00
Calculated analysis		
ME, kcal/lb	1534	1535
Crude protein, %	18.4	13.9
Total lysine, %	1.00	0.97
TID amino acids, %		
Lysine, %	0.88	0.88
Threonine, %	0.60	--
Methionine, %	0.27	0.31
Tryptophan, %	0.19	0.18
Isoleucine, %	0.69	0.53
Leucine, %	1.49	1.22
Ca, %	0.87	0.83
P, %	0.78	0.74
Available P, %	0.48	0.48

[a]All diets are formulated to contain 0.88% TID lysine.
[b]Corn-soybean meal diet containing 0.60% TID threonine.
[c]Crystalline amino acid diets are formulated to contain increasing TID threonine concentrations of 0.44, 0.50, 0.57, 0.64, and 0.70%. L-threonine was added to the crystalline amino acid diets at the expense of sand to achieve desired TID threonine content.

Table 2. Effects of Increasing Dietary True Ileal Digestible Threonine During Lactation on Sow Performance

		True Ileal Digestible Threonine (%)[g]						Probability, P <[f]		
Item	Control[h]	0.44[i]	0.50[i]	0.57[i]	0.64[i]	0.70[i]	SE	Linear	Quadratic	Corn-SBM vs. Crystallines
Number of sows	31	28	31	31	32	29				
Lactation length, d	21.3[a]	21.3[ab]	21.2[ab]	20.9[bc]	20.8[c]	21.0[ab]	0.21	0.07	0.28	0.12
ADFI, lb	11.1[a]	11.6[ab]	12.2[b]	12.1[b]	12.1[b]	12.0[ab]	1.2	0.57	0.41	0.05
Sow weight, lb										
Day 2	530.2	531.4	519.6	528.5	520.6	545.2	44.8	0.48	0.18	0.87
Weaning	496.9	500.5	491.9	501.4	493.7	512.1	53.7	0.42	0.31	0.77
Loss	33.2	29.9	28.5	27.6	27.0	29.0	9.3	0.86	0.53	0.37
Backfat										
Day 2	14.6	14.8	14.5	15.2	15.1	14.3	0.7	0.93	0.50	0.85
Weaning	11.9	12.4	11.3	12.9	12.2	11.9	0.5	0.99	0.69	0.59
Loss	2.8[ab]	2.3[ab]	3.1[a]	2.2[b]	2.9[ab]	2.3[ab]	0.7	0.87	0.49	0.60
PUN	5.60	4.42[a]	4.00[a]	4.49[a]	4.51[a]	4.53[a]	0.3	0.35	0.67	0.01

[abc]Means on the same row without common superscripts differ, P<0.10.

[f]Linear and quadratic probability refer to increasing TID threonine.

[g]All diets are formulated to contain 0.88% TID lysine.

[h]Corn-soybean meal diet containing 0.60% TID threonine.

[i]Crystalline amino acids used in diets.

Table 3. Effects of Increasing Dietary True Ileal Digestible Threonine During Lactation on Litter Performance

		True Ileal Digestible Threonine (%)[g]						Probability, P <[f]		
Item	Control[h]	0.44[i]	0.50[i]	0.57[i]	0.64[i]	0.70[i]	SE	Linear	Quadratic	Corn-SBM vs. Crystallines
Number of sows	31	28	31	31	32	29				
Day 2 No. pigs	11.2[a]	10.9[ab]	11.4[ab]	11.3[ab]	11.6[b]	11.5[b]	0.2	0.11	0.22	0.69
Day 2 litter wt.	36.9	35.2	36.7	36.3	37.4	36.9	1.2	0.28	0.35	0.59
No. of pigs weaned	10.5	10.1	10.6	10.5	10.5	10.5	0.3	0.51	0.17	0.66
Litter weaned wt.	148.3	142.4	149.6	145.0	146.6	140.1	5.8	0.69	0.17	0.39
Litter wt. gain	111.4	107.2	112.9	108.7	109.1	103.26	5.0	0.46	0.19	0.39
Pre-weaning mortality, %	5.94	8.00	6.39	7.20	9.15	8.89	0.02	0.44	0.58	0.31

[abc]Means on the same row without common superscripts differ, P<0.10.

[f]Linear and quadratic probability refer to increasing TID threonine.

[g]All diets are formulated to contain 0.88% TID lysine.

[h]Corn-soybean meal diet containing 0.60% TID threonine.

[i]Crystalline amino acids used in diets.

IS THE TOTAL SULFUR AMINO ACID:LYSINE RATIO FOR LACTATING SOWS GREATER THAN 50%?

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

Summary

A total of 75 lactating sows were used in a study to determine whether the ratio of total sulfur amino acid (TSAA) to lysine calculated from the NRC (1998) is adequate for lactating sows. Low and high sulfur amino acid diets were formulated to contain a (true ileal digestible (TID) TSAA content of 0.44 or 0.57%, respectively. Both experimental diets were based on corn and soybean meal and were formulated to contain 0.88% TID lysine (0.97% total lysine). Thus, the TID TSAA:lysine ratios were 50 and 65% for the two experimental diets, respectively. Both experimental diets contained 0.37% L-lysine HCl, with other amino acids (isoleucine, threonine, tryptophan, and valine) added to ensure that TSAA were the first limiting amino acids. Sows were farrowed in three farrowing groups and were randomly allotted to the dietary treatments on the basis of parity. The lactating sows fed the 0.57% TSAA diet had greater ADFI than did sows fed the 0.44% TSAA diet ($P<0.05$). Sow weight loss was not affected by lactation treatment, but sows fed the diet with more TSAA had greater ($P<0.02$) litter weight gain, heavier ($P<0.01$) litter weaning weights, and heavier ($P<0.06$) individual pig weaning weight than did sows fed the 0.44% TSAA diet. These data indicate that the basal diet can be used in future experiments to titrate the TSAA requirement of the sow. Results also indicate that the TID TSAA requirement is greater than 0.44% and the TSAA:lysine ratio is greater than 50% for lactating sows. Because amino acid recommendations from the NRC (1998) suggest that the TID TSAA:lysine ratio is approximately 48%, more research is warranted to more adequately determine the TID TSAA:lysine ratio for lactating sows.

(Key Words: TSAA, Lysine, Lactating Sow.)

Introduction

Due to increased litter size and milk production in modern sows, the requirements for amino acids have changed. The requirements for essential amino acids other than lysine are typically predicted from the amount secreted in milk and available from body protein. The drawback of establishing essential amino acid requirements in this manner is that not all amino acids are used for milk protein production, with some used for protein deposition and turnover. Along with conversion into protein, methionine also can be converted to S-adenosylmethionine, which acts as a methylating substrate for synthesis of other metabolites. Furthermore, we are only aware of one published study that examines the requirement of sulfur amino acid for the lactating sow. As a consequence, there is little knowledge of the total sulfur amino acid (TSAA) requirement of the modern lactating sow. Calculations based on NRC (1998) recommendations result in a

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

TID TSAA:lysine ratio of approximately 48 to 49%, depending on the level of milk production. The objective of this experiment was to determine whether the TSAA:lysine ratio calculated from NRC (1998) recommendations is adequate for lactating sows. A secondary objective was to determine whether deleting methionine from a diet containing large amounts of synthetic amino acids would alter sow productivity, thus, providing a model to determine the TSAA:lysine ratio for lactating sows in future experiments.

Procedures

This study was conducted in the Kansas State University Swine Teaching and Research Center farrowing facilities. Seventy-five sows were blocked by parity and allotted to one of two diets. The 75 sows used in this study were PIC Line 1050 and were farrowed in three farrowing groups. Sows were randomly assigned to treatments balanced by parity when entering the farrowing house on day 110 of gestation. During lactation, sows were provided *ad libitum* access to feed and water, and feed disappearance was recorded. All sows were fed diets that contained large amounts of synthetic amino acids and contained either 0.44 or 0.57% TID TSAA (Table 1). The two diets were identical except that DL-methionine replaced sand in the 0.57% TSAA diet. The diets were formulated to contain 0.88% TID lysine and 1,537 kcal of ME per lb (Table 2).

All sows were weighed after farrowing and again at weaning to calculate weight change during lactation. Cross-fostering occurred before day 2 to standardize all litters with approximately 11 pigs. Pigs were weighed individually at birth, after fostering on day 2, and again at weaning. Any pigs removed from the trial were recorded, along with their date of removal and weight. Litters did not have access to supplemental milk or creep feed. Data were analyzed by using the MIXED procedure of SAS.

Results and Discussion

The lactating sows fed the diet containing 0.57% TID TSAA had greater ($P<0.05$) ADFI than did sows fed the diet containing 0.44% TID TSAA (Table 2). Sow weight loss during lactation was not affected by treatment. Litters weaned from sows fed the 0.57% TSAA diet were heavier ($P<0.01$; Table 2) than litters weaned from sows fed the 0.44% TSAA diet. The marked difference in litter weaning weight was due to the increase ($P<0.02$) in litter weight gain. At weaning, pigs reared from sows fed more TSAA averaged 13.7 lb, heavier ($P<0.06$) than the 12.8 lb averaged by pigs reared from sows fed the 0.44% TSAA diet. Litter size averaged 9.9 pigs during lactation, and mortality rate was 8.1 and 7.7% for the diets with 0.44% TSAA and 0.57% TSAA, respectively.

It is clear in this study that the sows required more than 0.44% TID TSAA. The TSAA:lysine ratio in this diet was 50%. Increasing the TSAA content to 0.57% (65% TSAA:lysine ratio) increased sow feed intake, pig weaning weight, and litter weight gain.

One concern with expressing the TSAA content on a ratio to lysine is making sure that the sows were not fed in excess of their lysine requirement. To support the 138-lb litter weaning weight and 101 lb of litter weight gain from d 2 to 21 without losing body protein, sows would have had to consume more than 54 g of TID lysine per day. With ADFI of approximately 11.5 lb/day, sows on the diets with 0.57% TSAA actually consumed approximately 46 g of TID lysine per day. Thus, sows received less than their lysine requirement, making amino acid ratio comparisons valid.

The current NRC (1998) requirement estimates for a TID TSAA:lysine ratio is calculated to be approximately 48%. Our results suggest that the NRC ratio is too low and that the requirement for these high-producing sows was greater than 50%. The large magnitude of the response suggests that the optimum ratio is probably significantly greater than 50%. These data also validate that our basal diet can be used in future research to titrate the optimal TSAA:lysine ratio for lactating sows.

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

Item	Basal Diet[b]
Corn	76.09
Soybean meal (46.5% CP)	16.00
Soybean oil	2.50
Monocalcium P (21% P, 18% Ca)	2.00
Limestone	1.00
Salt	0.50
Vitamin premix	0.25
Trace mineral premix	0.15
Sow add pack	0.25
L-valine	0.31
L-isoleucine	0.04
L-tryptophan	0.05
L-threonine	0.20
L-lysine HCl	0.37
DL-methionine	---
Sand	0.30
Total	100.00
Calculated analysis	
ME, kcal/lb	1535
Crude protein, %	13.9
Total lysine, %	0.97
TID amino acids, %	
Lysine	0.88
Methionine	0.21
Methionine & Cystine	0.44
Threonine	0.64
Tryptophan	0.18
Isoleucine	0.53
Leucine	1.21
Ca, %	0.80
P, %	0.70
Available P, %	0.50

[a]All diets are formulated to contain 0.88% TID lysine.
[b]DL-methionine was added at the expense of sand to achieve the desired TID TSAA content of 0.57%.

Table 2. Effects of Increasing Dietary True Ileal Digestible TSAA During Lactation

	True Ileal Digestible TSAA (%)[a]			Probability,
Item	0.44	0.57	SE	P <
Number of sows	38	37		
Lactation length, d	20.4	20.0	0.38	0.32
ADFI, lb	10.3	11.5	0.39	0.04
Sow weight, lb				
Day 2	526.2	512.6	9.67	0.33
Weaning	476.8	463.7	8.63	0.29
Loss	49.6	48.9	5.85	0.94
Day 2 No. pigs	10.6	11.0	0.26	0.23
Day 2 litter wt.	34.9	37.1	0.94	0.11
Day 2 avg. pig wt.	3.3	3.4	0.09	0.57
Litter weaned wt.	123.1	137.9	4.07	0.01
Litter wt. gain	88.1	100.9	3.77	0.02
Avg. weaned pig wt.	12.8	13.7	0.34	0.06
Pre-weaning mortality, %	8.1	7.7	0.02	0.86

[a]All diets are formulated to contain 0.88% TID lysine.

INFLUENCE OF FEEDING WEANMOR+® TO SOWS ON STILLBORN RATE AND PREWEANING MORTALITY[1]

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

Summary

A total of 239 sows (PIC C-22) were used in this experiment. Sows were randomly allotted to one of the two experimental treatments approximately 5 days before their expected farrowing date. Control sows did not receive any topdress; sows on the WEANMOR+® treatment received a single daily topdress of 25 g of WEANMOR+®. Topdressing the sow feed with WEANMOR+® reduced ($P<0.06$) urine pH, but number of total pigs born, mummied, fostered, died, or weaned were not influenced by treatment ($P>0.67$). There was a parity group-by-stillborn interaction ($P<0.10$) in which feeding WEANMOR+® reduced the number of stillborn pigs in the parity 2 to 5 sows, with a numeric increase in stillborns when WEANMOR+® was fed to sows that were parity 6 and over.

(Key Words: Sows, Litter Size, Diet Acidification.)

Introduction

WEANMOR+® is a product produced by Soda Feed Ingredients. It is a microencapsulated, dry calcium chloride product. The chloride ions are thought to improve the cation/anion balance and lower the pH in the GI tract and urine. Because pH decreases, development of bacteria in the GI tract is also changed, which may reduce preweaning mortality. In addition, because calcium is required for muscle contraction during farrowing, the extra calcium provided by WEANMORE+® may help with muscle contractions. We conducted a previous experiment providing limestone as a topdress and found no difference in stillbirths, but the change in calcium source and incorporation in a protected product may alter the response. Topdressing WEANMOR+® reduced stillbirths in a previous experiment and increased milk yield when fed at .4% of the complete diet in another experiment. Therefore, the objective of this trial was to determine whether feeding WEANMOR+® to sows immediately before farrowing and during lactation reduces stillbirths and preweaning mortality.

Procedures

A total of 239 sows (PIC C-22) were used in this experiment. Sows were randomly allotted to one of the two experimental treatments approximately 5 days before their expected farrowing date. Control sows did not receive any topdress. Sows on the WEANMOR+®

[1]Appreciation is expressed to Rod and Ellen Evert and the other employees at Zenith Project, Genesco, Kansas, for data collection, and to Dr. Lisa Tokach from Kansas Swine Alliance for assistance in experimental design and data collection. Appreciation also is expressed to Soda Feed Ingredients for partial financial support of the experiment.

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

treatment received a single daily topdress of 25 g of WEANMOR+®. Before sows were moved to the farrowing house, the WEANMOR+® was added on top of the gestation diet. After sows were moved to the farrowing house, the WEANMOR+® was added on top of the lactation diet. The goal was to feed the WEANMOR+® for 4 to 5 days before parturition.

Sow farrowing cards were marked with the treatment (C for control or T for topdress). When entered into PigChamp, the C or T was recorded as a flag for each individual sow, followed by the day of initial treatment. The date that sows were moved into the farrowing house was marked on the sow card and entered into PigChamp. Because preweaning mortality was an important criterion in the experiment, cross-fostering was only done within treatment. If foster sows were created, they received pigs only from one treatment.

Response criteria were total born, stillborn, mummies, whether or not the sow required assistance during farrowing, and preweaning mortality. Litter weaning weight also was measured. Urine samples were collected on a subsample of 40 sows (approximately 20 sows per treatment), and urine pH was measured immediately with a portable pH meter. Urine was collected within 24 hours after sows completed farrowing.

Because classification of a pig as stillborn versus a pig that was born alive and died shortly after birth was very important, standard definitions were used. A stillborn was defined as a piglet that was alive at the initiation of farrowing, but died intrapartum. Piglets showing autolytic changes were classified as mummies. Piglets that seemed full-term, but may have died postpartum, were counted in preweaning mortality rates. A fully formed pig that had no signs of having breathed air was classified as a stillborn. Mummies were defined as fetuses that die after the onset of skeletal calcification (30 to 40 days of gestation), but before initiation of parturition. These typically are the inspissated remains of fetal tissues after the maternal uterus has removed bodily fluids, leaving only the nonabsorbable parts.

Data were analyzed by using the Proc Mixed procedures of SAS. Room and parity group (parity 1, parity 2 to 5, or parity 6 to 10) were used as covariates in the analysis. The small number of animals in some parity subgroups prevented the use of parity alone as a covariate. Therefore, sows were divided into three groupings to attempt to account for the increased stillbirths that normally occur in high-parity sows and small number of stillbirths in first-parity sows. To further investigate the data, a potential parity group-by-treatment interaction for stillbirths was also explored in a subsequent analysis.

Results and Discussion

Topdressing the sow feed with WEANMOR+® reduced ($P<0.06$) urine pH as expected (Table 1). Number of total pigs born, mummied, fostered, died, or weaned were not influenced by treatment (Table 2). The number of stillborn pigs was numerically fewer for sows topdressed with WEANMOR+®, but the differences were not significant. If the standard deviation from stillbirth number in this data set (1.44) is used, the calculated sample size for the 0.18 pig-per-litter reduction in stillbirths would be approximately 1,600 sows per treatment. Weaning weight also was not influenced by WEANMOR+®.

Because parity group was used as a covariate, we investigated whether the number of stillborn pigs was influenced by parity group (Table 3). There was a parity group-by-stillborn interaction ($P<0.10$) in which feeding WEANMOR+® reduced the number of still-

born pigs in the parity 2 to 5 sows, with a numeric increase in stillborns when WEANMOR+® was fed to sows that were parity 6 and over.

Even though relatively few pigs from the experiment were fostered onto nurse sows, we believed it was important to provide a full accounting of the fate of these pigs that were fostered off of sows on the experimental treatments. There unfortunately were not enough fostered pigs to allow for statistical analysis, and we were not able to attribute their data back to the source litter for statistical analysis as part of the source litter. Therefore, we have provided the raw data for the total number of pigs fostered, those that were fostered and lived, and the calculation of number of pigs produced per sow farrowed (Table 4). This calculation indicates that topdressing with WEANMOR+® numerically increased the number of pigs weaned per sow farrowed by 0.29 pigs. If the standard deviation of number weaned per sow from this data set (1.39) is used, the calculated sample size to find a difference of 0.29 pigs would be approximately 600 sows per treatment. Thus, the difference would not have been significantly different in this experiment.

In conclusion, topdressing the feed with WEANMOR+® from 5 days before farrowing until weaning did not influence sow productivity in this experiment. But this product was effective in lowering urine pH, and the stillbirth interaction between parity group and treatment, which indicated a potential benefit in parity 2 to 5 sows, warrants further investigation.

Table 1. Influence of WEANMOR+® on Sow Urine pH

Item	Control	WEANMOR+®	SE	P <
Number of sows	18	22		
Average urine pH	6.75	6.28	.18	0.06

Sows received WEANMOR+® for an average of 5.7 days before collection of urine.

Table 2. Influence of WEANMOR+® on Sow and Litter Performance

Item	Control	WEANMOR+®	SE	P <
Number of sows	118	121		
Average parity	4.5	4.3		
Total born, n	13.3	13.2	0.32	0.78
Stillborn, n	1.25	1.08	0.29	0.35
Mummies, n	0.60	0.58	0.17	0.82
Net fosters, n	-0.68	-0.83	0.31	0.67
Pigs died, n	1.46	1.43	0.15	0.89
Number weaned	9.23	9.19	0.13	0.81
Weaning weight, lb	127.5	127.4	3.00	0.97
Lactation length	19.1	19.4	0.37	0.39
Days on Weanmor+® before farrowing	5.11	5.11	0.62	0.97

Table 3. Influence of WEANMOR+® on Litter Stillborn Rate

Item	Control	WEANMOR+®	SE
Number of sows			
Parity 1	8	9	
Parity 2 to 5	72	78	
Parity 6 to 10	38	33	
Stillborn, n[a]			
Parity 1	0.57	0.61	0.50
Parity 2 to 5	1.37	0.91	0.18
Parity 5 to 10	1.42	1.82	0.25

[a]Interaction P< 0.10; parity group P < 0.01; treatment P < 0.98.

Table 4. Influence of WEANMOR+® on Number of Pigs Produced

Item	Control	WEANMOR+®
Total pigs fostered off	81	103
Fostered pigs that lived and were weaned	52	93
Total pigs weaned from original sows	1090	1113
Total pigs produced (foster and weaned)	1142	1206
Pigs produced per litter farrowed	9.68	9.97
Difference	---	0.29

COMPARISON OF WATER-BASED AND IN-FEED ANTIMICROBIALS FOR GROWTH PERFORMANCE ENHANCEMENT OF WEANLING PIGS

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

Summary

A total of 350 weanling pigs (initially 13.0 lb and 14 ± 3 d of age, PIC) were used to determine the effects of water-based antimicrobial on nursery pig growth performance. Pigs were given one of 5 experimental treatments: negative control (no antibiotics in the feed or water), positive control diet containing Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl), Neomycin sulfate in the water (24.2 mg of Neomycin sulfate per L), Oxytetracycline in the water (24.2 mg of Oxytetracycline per L), and Neomycin sulfate and Oxytetracycline (Neo/oxy) in the water. Overall (d 0 to 28 after weaning), pigs provided a water antimicrobial had greater ADG ($P<0.01$) and ADFI ($P<0.02$) than did pigs provided non-medicated water and feed. But pigs fed diets containing Neo-Terramycin® had greater ADG and ADFI ($P<0.01$) than did pigs provided a water antimicrobial. Pigs provided water containing Neomycin sulfate or Neo/oxy had greater ADG and ADFI ($P<0.05$) than did pigs provided non-medicated feed and water, and ADG and ADFI of pigs provided water containing Oxytetracycline were intermediate. There were no differences in growth performance between water antimicrobials and no differences in F/G for all treatments.

(Key Words: Nursery Pig, Antibiotics, Water, Growth.)

Introduction

The use of in-feed antimicrobials in nursery pig diets has long been recognized as a method to improve growth performance and health. But the use of these feed additives poses several challenges to swine production systems. First, changing the type of antimicrobial can be difficult due to feed-processing limitations. Second, handling multiple antibiotics in the mill leads to multiple runs of feed and concerns with cross-contamination with non-medicated feed. Third, pulsing antibiotics can be very difficult with feed application due to the difficulty of timing the delivery of the feed. Replacing in-feed with water-based antimicrobials would simplify feed processing and reduce the risk of feed being contaminated with an inappropriate antimicrobial or antimicrobial residue. Therefore, we conducted this trial to evaluate the effectiveness of water-based antimicrobials as a potential replacement for typical feed delivery of antimicrobials for improving nursery growth performance.

Procedures

A total of 350 weanling pigs (initially 13.0 lb and 14 ± 3 d of age, PIC) were blocked by

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

initial weight and randomly allotted to one of five dietary treatments. Two adjacent pens used the same water line and served as one experimental unit. There were 5 pigs per pen and 7 experimental units (14 pens) per treatment. Pigs remained on the same treatments for 28 d after weaning. The five experimental treatments were: negative control (no antibiotics in the feed or water, positive control diet containing Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl), Neomycin sulfate in the water, Oxytetracycline in the water, or Neomycin sulfate and Oxytetracycline in the water (Neo/Oxy). When used, 12.5 ml of Neomycin liquid (200 mg/ml Neomycin sulfate) was provided per L of water and was then diluted to a concentrate:water ratio of 1:100. This provided 24.2 mg of Neomycin sulfate per L of drinking water. Oxytetracycline powder was provided at 45.35 g (55.1 mg of oxytetracycline per g) per L, and was then diluted to a concentrate:water ratio of 1:100, equivalent to 24.2 mg of Oxytetracycline per L of drinking water. For the Neo/Oxy treatment, the water contained 24.2 mg of Neomycin sulfate and 24.2 mg of Oxytetracycline per L. Pigs that received water-based antibiotics were fed the negative control diet that did not contain an antibiotic.

Water-based antimicrobials were administered through SelectDoser™ peristaltic pumps (Genesis Instruments; Elmwood, WI). This type of doser is powered by electricity, and siphons a concentrated, pre-mixed stock solution through a tube and doses the antimicrobial into the existing water supply. Concentrated stock solutions were made once every two days throughout the experiment. Each solution consisted of 4 L of water and either 50 ml Neomycin (12.5 ml/L), 181.4 g Oxytetracycline (45.35 g/L), or a combination of 50 ml Neomycin and 181.4 g Oxytetracycline. These concentrated stock solutions were dosed into the existing water line at a ratio of 1:100 to achieve the desired amount of antimicrobial.

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 after 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 segregated early-weaning nursery facility at Kansas State University. 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, ADFI, and F/G were determined by weighing pigs and feeders on d 0, 7, 14, and 28 after weaning. In addition, water disappearance was measured. Growth performance data were analyzed as a randomized complete-block design, with pair of pens 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 provided a water antimicrobial had greater ADG ($P<0.02$) and improved F/G ($P<0.03$), and tended to have increased ADFI ($P<0.08$), compared with those of pigs fed non-medicated feed or water. But pigs fed diets containing Neo-Terramycin® had greater ADG and ADFI ($P<0.01$) than did pigs provided a water antimicrobial. Pigs provided water containing Neomycin sulfate or Neo/oxy had greater ADG and ADFI ($P<0.05$) than those of pigs provided non-medicated water and feed, and those of pigs provided water containing Oxytetracycline were intermediate. Pigs fed diets containing Neo-Terramycin® had greater ADG and ADFI ($P<0.05$) than did pigs provided water containing Oxytetracycline provided or non-medicated feed and water. Pigs provided water containing Neo/oxy or diets containing Neo-Terramycin® had improved F/G ($P<0.05$), compared with F/G of pigs pro-

vided non-medicated feed and water; results of all other treatments were intermediate.

From d 14 to 28, pigs provided a water antimicrobial had greater ADFI ($P<0.02$) and tended to have greater ADG ($P<0.11$) than did pigs provided non-medicated feed and water, but pigs fed diets containing Neo-Terramycin® had greater ADFI ($P<0.01$) and ADG ($P<0.03$) than did pigs provided a water antimicrobial. Pigs fed diets containing Neo-Terramycin® had greater ADG ($P<0.05$) than did pigs provided water containing Neo/oxy or provided non-medicated feed and water; ADG of pigs provided water containing Neomycin sulfate or Oxytetracycline was intermediate. Pigs provided water containing Neomycin sulfate had greater ADFI ($P<0.05$) than did pigs provided non-medicated feed and water; ADFI of pigs provided water containing Oxytetracycline or Neo/oxy was intermediate. Pigs provided water containing Oxytetracycline had improved F/G ($P<0.05$), compared with that of pigs fed diets containing Neo-Terramycin® or those provided water containing Neo/oxy; F/G of pigs provided water containing Neomycin sulfate or provided non-medicated feed and water was intermediate.

Overall (d 0 to 28 after weaning), pigs provided a water antimicrobial had greater ADG ($P<0.01$) and ADFI ($P<0.02$) than did pigs provided non-medicated water and feed, but pigs fed diets containing Neo-Terramycin® had greater ADG and ADFI ($P<0.01$) than did pigs provided a water antimicrobial. Pigs provided water containing Neomycin sulfate or Neo/oxy had greater ADG and ADFI ($P<0.05$) than did pigs provided non-medicated feed and water; results of pigs provided water containing Oxytetracycline were intermediate. There were no differences in growth performance between water antimicrobials and no differences in F/G for all treatments.

Water disappearance was variable, but much greater than expected. In typical commercial nurseries using bowl waterers, expected water disappearance is around 20% of pig body weight (BW). In our experiment, water disappearance was approximately 36.4% of BW during the first week of the trial, and gradually declined to 22.8% by d 28. Nipple waterers (without guards) were used in our experiment. As a result, the increased water usage is most likely due to accidental pressure on the nipple during non-drinking activities, causing wastage. In addition, it was observed that a considerable amount of water was wasted during the normal drinking process.

Water antimicrobial concentrations were based on predicted water consumption, without accounting for wastage. As a result of increased wastage, pigs provided water antimicrobials most likely did not receive the desired amount of antimicrobial per pound of body weight. Furthermore, pigs provided an antimicrobial through the water received an overall lower dosage than did pigs provided antimicrobial through the feed because of the unexpected wastage. In more recent experiments in the same facility, in which bowl waterers and various rates of water antimicrobials were used, there was no significant difference in growth performance between pigs provided an antimicrobial through the water or the feed. In those experiments there was decreased wastage at the waterer and, thus, an increase in the actual amount of antimicrobial to the pig.

The use of a water-based antimicrobial resulted in improved growth performance, compared with that of pigs fed feed and water without antimicrobials. Water disappearance by all pigs was greater than expected and may have resulted in decreased antimicrobial consumption, compared with that of pigs provided feed antimicrobial. For example, if actual

water consumption was assumed to be 10% of BW, those pigs provided a water-based antimicrobial consumed 65.8 mg/pig/d, compared with 207.2 mg/pig/day from the feed-based antimicrobial, for the overall treatment period. Further research is needed to determine if the same rate of growth performance can be obtained when water-based or feed-based antimicrobials are provided at the same dosages.

Table 1. Diet Composition (As-fed Basis)

Ingredient, %	Phase 1[a]		Phase 2[b]	
	Negative Control	Positive Control	Negative Control	Positive Control
Corn	48.42	48.42	60.32	60.32
Soybean meal (46.5% CP)	28.98	28.98	34.98	34.98
Spray dried whey	15.00	15.00	---	---
Select menhaden fish meal	3.75	3.75	---	---
Monocalcium P (21% P)	1.15	1.15	1.60	1.60
Limestone	0.70	0.70	1.10	1.10
Salt	0.33	0.33	0.33	0.33
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-threonine	0.13	0.13	0.13	0.13
DL-methionine	0.15	0.15	0.15	0.15
Lysine HCl	0.30	0.30	0.30	0.30
Test ingredient[c]	0.70	0.70	1.00	1.00
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Total lysine, %	1.55	1.55	1.45	1.45
True digestible amino acids				
Lysine	1.41	1.41	1.31	1.31
Isoleucine:lysine ratio, %	60	60	63	63
Leucine:lysine ratio, %	120	120	129	129
Methionine:lysine ratio, %	34	34	33	33
Met & cys:lysine ratio, %	57	57	57	57
Threonine:lysine ratio, %	62	62	63	63
Tryptophan:lysine ratio, %	17	17	18	18
Valine:lysine ratio, %	65	65	69	69
ME, kcal/lb	1,494	1,481	1,497	1,484
CP, %	21.8	21.8	21.4	21.4
Ca, %	0.90	0.90	0.85	0.85
P, %	0.80	0.80	0.75	0.75
Available P, %	0.52	0.52	0.42	0.42

[a]Fed from d 0 to 14 after weaning.
[b]Fed from d 14 to 28 after weaning.
[c]Corn starch or Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).

Table 2. Growth Performance of Early-weaned Nursery Pigs Provided Water-based Antimicrobials[a]

Item	Neg Control	Neo/Oxy Feed[f]	Water Antimicrobial			Probability, P<			
			Neo[g]	Oxy[h]	Neo/Oxy[i]	Trt	Neg. Control vs. Water Antimicrobials	Neo/Oxy Feed vs. Water Antimicrobials	SE
d 0 to 14									
ADG, lb	0.63[b]	0.77[d]	0.70[bcd]	0.65[bc]	0.73[cd]	0.01	0.02	0.01	0.030
ADFI, lb	0.83[b]	0.95[d]	0.89[cd]	0.84[bc]	0.89[cd]	0.01	0.08	0.01	0.030
F/G	1.32[b]	1.23[cd]	1.27[bcd]	1.29[bc]	1.22[d]	0.02	0.03	0.19	0.031
d 14 to 28									
ADG, lb	1.29[b]	1.40[c]	1.35[bc]	1.35[bc]	1.31[b]	0.03	0.11	0.03	0.031
ADFI, lb	1.81[b]	2.00[d]	1.91[c]	1.87[bc]	1.88[bc]	0.01	0.02	0.01	0.036
F/G	1.40[bc]	1.43[c]	1.41[bc]	1.38[b]	1.43[c]	0.17	0.62	0.24	0.023
d 0 to 28									
ADG, lb	0.96[b]	1.08[d]	1.02[c]	1.00[bc]	1.02[c]	0.01	0.01	0.01	0.022
ADFI, lb	1.32[b]	1.48[d]	1.40[c]	1.35[bc]	1.39[c]	0.01	0.02	0.01	0.028
F/G	1.37	1.36	1.36	1.35	1.36	0.81	0.30	0.92	0.019

[a]A total of 350 weanling pigs, initially 13.0 lb (PIC); Each mean consists of 7 experiment units (pair of pens served by the same water line).

[bcde]Means in the same row with different superscripts differ.

[f]Neo/Oxy (Neo-Terramycin® providing 140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).

[g]Neomycin sulfate (24.2 mg/L).

[h]Oxytetracycline (24.2 mg/L).

[i]Neo/Oxy combination (24.2 mg/L Neomycin sulfate, 24.2 mg/L Oxytetracycline HCl).

Table 3. Water Disappearance of Early-weaned Pigs Provided Water-based Antimicrobials (% BW)[a]

Item	Neg. Control	Neo/Oxy Feed[b]	Water Antimicrobial			Overall Mean
			Neo[c]	Oxy[d]	Neo/Oxy[e]	
d 0 to 7	34.9	33.5	35.4	39.3	38.9	36.4
d 7 to 14	30.3	27.4	26.9	37.0	35.7	31.5
d 14 to 21	22.0	20.3	25.9	26.9	28.8	24.8
d 21 to 28	21.4	19.7	24.9	23.9	24.3	22.8
d 0 to 28	27.2	25.2	28.3	31.8	31.9	28.9

[a]A total of 350 weanling pigs, initially 13.0 lb (PIC); Each mean consists of 7 experiment units (pairs of pens served by the same water line).
[b] Neo/Oxy (Neo-Terramycin® providing 140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).
[c]Neomycin sulfate (24.2 mg/L).
[d]Oxytetracycline (24.2 mg/L).
[e]Neo/Oxy combination (24.2 mg/L Neomycin sulfate, 24.2 mg/L Oxytetracycline HCl).

EFFECTS OF DIFFERENT DOSAGES OF WATER-BASED NEOMYCIN SULFATE ON GROWTH PERFORMANCE OF WEANLING PIGS

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

Summary

A total of 360 weanling pigs (initially 14.1 lb and 21 ± 3 d of age, PIC) were used to determine the effects of different rates of water-based medication on nursery pig growth performance. Pigs were given one of eight experimental treatments: negative control (no antibiotics in the feed or water); positive control with Neo-Terramycin® in the feed (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl); 38.0, 75.5, or 113.5 mg of Neomycin sulfate per L of water; 100 or 200 g/ton of Neomycin sulfate in the feed; and Neo-Terramycin® in the feed and 75.5 mg of Neomycin per L of water. Overall (d 0 to 24 after weaning), pigs provided Neomycin sulfate in the water, pigs fed diets containing Neomycin sulfate, and pigs fed the positive control diet had greater ADG (P<0.02) and ADFI (P<0.05) than did pigs provided non-medicated water and feed. Pigs provided Neomycin sulfate in the water or feed also had improved F/G (P<0.05), compared with the F/G of pigs provided non-medicated feed and water. Pigs provided the combination of the positive control diet and Neomycin sulfate in the water had greater ADFI (P<0.04) and tended to have greater ADG (P<0.09) than did pigs fed the positive control with non-medicated water or pigs fed the negative control with Neomycin sulfate in the water. Increasing Neomycin sulfate in the water improved ADG (P<0.03) and ADFI (P<0.05). Increasing Neomycin sulfate in the feed improved ADG and ADFI (P<0.01) and improved F/G (P<0.03). There were no differences in growth performance between pigs provided Neomycin sulfate in the water and in the feed. Finally, there were no water medication × feed medication interactions for the overall treatment period, but main effects for water and feed medication were significant (P<0.02) for ADG and ADFI.

(Key Words: Nursery Pig, Antibiotics, Water, Growth.)

Introduction

A recent trial conducted at the Kansas State University SEW facility showed that the use of water-based medication for nursery pigs improved growth performance over that of pigs fed non-medicated feed and water. When compared with pigs fed in-feed medication, however, growth differences were not significant. The response shown by including medication in the water indicated the potential for improved growth performance at slightly larger doses and warranted further research to determine what dosages are optimal to meet or exceed the growth response shown in weanling pigs fed medication via the feed. Therefore, the objective of this experiment was to determine the optimal dosage of water-

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

based Neomycin sulfate for weanling pigs and determine if it provides similar growth performance when fed separately or in combination with different amounts of in-feed medication.

Procedures

A total of 360 weanling pigs (initially 14.1 lb and 14 ± 3 d of age, PIC) were blocked by initial weight, and randomly allotted to one of eight dietary treatments. Individual bowl waterers replaced pairs of nipple waterers in the facility to allow the use of each pen as an experimental unit. There were 5 pigs per pen and 9 pens per treatment. Pigs remained on the same treatments for 24 d after weaning. There were eight experimental treatments: negative control (no antibiotics in the feed or water); positive control with Neo-Terramycin® in the feed (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl); 38.0, 75.5, or 113.5 mg of Neomycin sulfate per L of water; 100 or 200 g/ton Neomycin sulfate; and Neo-Terramycin® in the feed and 75.5 mg of Neomycin sulfate per L of water. When used, 19, 37.75, and 56.75 ml of Neomycin (200 mg/ml Neomycin sulfate) was provided per L of water, which provided 38.0, 75.5, and 113.5 mg, respectively, of Neomycin sulfate per L of water. Pigs that received only water-based antibiotics were fed the negative control diet that did not contain an antibiotic.

Water-based medication was administered through SelectDoser™ peristaltic pumps (Genesis Instruments; Elmwood, WI). This type of doser is powered by electricity, and siphons a concentrated, pre-mixed stock solution through a tube and doses the medication into the existing water supply. Concentrated stock solutions were made once every two days throughout the experiment. Each solution consisted of citric acid (as a water-line cleaner and drug solubility aid) and 4 L of water, with either 76, 151, or 227 ml Neomycin. These concentrated stock solutions were dosed into the existing water line at a ratio of 1:100 to achieve the desired dosage of medication.

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 0.50% available phosphorus. Phase 2 (d 14 to 24 after weaning) diets were formulated to contain 1.31% TID lysine, 0.83% Ca, and 0.39% available phosphorus. The trial was conducted in an environmentally controlled segregated early-weaning nursery facility at Kansas State University. Each pen was 5 × 5 ft and contained one self-feeder and one bowl waterer to provide *ad libitum* access to feed and water. Average daily gain, ADFI, and F/G were determined by weighing pigs and feeders on d 7, 14, and 24 after weaning. In addition, water disappearance was measured. 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 provided Neomycin sulfate in the water or the feed had greater ADG and ADFI ($P<0.01$) than did pigs provided non-medicated water and feed. Pigs provided Neomycin sulfate in the water also tended to have improved F/G ($P<0.11$), and pigs fed the positive control diet with non-medicated water tended to have greater ADG ($P<0.08$), compared with that of pigs provided non-medicated water and feed. Pigs provided the combination of the positive control diet and Neomycin sulfate in the water (75.5 mg/L) tended to have greater ADG and ADFI ($P<0.07$) than did pigs fed the positive control with non-medicated water. Increasing Neomycin sulfate in the water improved ADG and ADFI (linear, $P<0.03$) as did increasing Neomycin sulfate in the feed (linear, $P<0.02$).

From d 14 to 24, pigs provided Neomycin sulfate in the feed had greater ADG and ADFI ($P<0.01$), and tended to have improved F/G ($P<0.10$), compared with that of pigs provided non-medicated water and feed. Also, compared with pigs provided non-medicated water and feed, pigs provided Neomycin sulfate in the water and pigs fed the positive control diet tended to have greater ADG and ADFI ($P<0.08$). Pigs provided the combination of the positive control diet and Neomycin sulfate in the water (75.5 mg/L) tended to have greater ADFI ($P<0.07$) than did pigs fed the positive control with non-medicated water, and they had greater ADFI ($P<0.01$) than did pigs provided 75.5 mg Neomycin sulfate per L of water and non-medicated feed. Although increasing Neomycin sulfate in the water did not affect growth performance from d 14 to 24 after weaning, increasing Neomycin sulfate in the feed improved ADG (linear, $P<0.01$) and ADFI (linear, $P<0.02$), and tended to improve F/G (linear, $P<0.07$).

Overall (d 0 to 24 after weaning), pigs provided Neomycin sulfate in the water, pigs fed diets containing Neomycin sulfate, and pigs fed the positive control diet had greater ADG ($P<0.02$) and ADFI ($P<0.05$) than did pigs provided non-medicated water and feed. Pigs provided Neomycin sulfate in the water or feed also had improved F/G ($P<0.05$), compared with that of pigs provided non-medicated feed and water. Pigs provided the combination of the positive control diet and Neomycin sulfate in the water (75.5 mg/L) had greater ADFI ($P<0.04$), and tended to have greater ADG ($P<0.09$), than did pigs fed the positive control with non-medicated water or pigs fed the negative control with 75.5 mg of Neomycin sulfate per L of water. Increasing Neomycin sulfate in the water improved ADG (linear, $P<0.03$) and ADFI (linear, $P<0.05$). Increasing Neomycin sulfate in the feed improved ADG and ADFI (linear, $P<0.01$), and improved F/G (linear, $P<0.03$). There were no differences in growth performance between pigs provided Neomycin sulfate in the water or in the feed. There were no water medication × feed medication interactions for the overall treatment period, but main effects for water and feed medication were significant ($P<0.02$) for ADG and ADFI.

As reported in a previous experiment, water disappearance was variable within time periods. In this experiment, however, water disappearance was very similar to that seen in commercial nurseries using bowl waterers. In our experiment, also using bowl waterers, water disappearance was relatively similar throughout the trial, with an overall (d 0 to 24 after weaning) average of 22.9% of pig body weight (BW). As a result of installing new bowl waterers in our facility, water usage decreased by nearly 21% from that in a previous experiment, in which nipple waterers were used (22.9 vs. 28.9 % BW)

Water medication consumed by pigs in a previous experiment was less than expected because of water wastage. In this experiment, medication concentrations were based on an estimated consumption of 10% of BW, rather than disappearance. This allowed for increased medication consumption by the pigs and, thus, a greater response to the water-based medication treatments.

In this experiment, liquid Neomycin sulfate was used for water-based medication. In addition, citric acid was used as a water-line cleaner and drug solubility aid. All pigs received water with the same concentration of citric acid. There were fewer plugged nipples throughout the trial period when using Neomycin sulfate and citric acid. Citric acid is thought to increase water intake, but the response to this factor was not measured in this experiment.

The use of Neomycin sulfate in the water or feed resulted in improved growth performance, compared with that of pigs fed non-medicated feed and water. No differences were found in growth performance of pigs provided medication by either method. This indicates that water-based medication can be used in place of medication in the feed to yield similar growth performance. Furthermore, water usage by all pigs was improved by installing bowl waterers, which in turn can potentially reduce the cost of water-based medication practices through increased efficiency. Further research is needed to evaluate the use of citric acid a water-line cleaner, solubility aid, and water intake stimulant. In addition, research is needed to evaluate the costs of providing various dosages of water-based Neomycin sulfate and the growth performance and water consumption of nursery pigs using similar treatment protocols.

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

Ingredient, %	Negative Control	Positive Control	Neomycin Sulfate	
			100 g/ton	200 g/ton
Corn	51.11	51.11	51.11	51.11
Soybean meal (46.5% CP)	30.16	30.16	30.16	30.16
Spray dried whey	10.00	10.00	10.00	10.00
Select menhaden fish meal	3.75	3.75	3.75	3.75
Soy oil	1.00	1.00	1.00	1.00
Monocalcium P (21% P)	1.20	1.20	1.20	1.20
Limestone	0.75	0.75	0.75	0.75
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-threonine	0.15	0.15	0.15	0.15
DL-methionine	0.13	0.13	0.13	0.13
Lysine HCl	0.30	0.30	0.30	0.30
Corn starch	0.70	---	0.65	0.60
Neo-Terramycin® [b]	---	0.70	---	---
Neomycin[c]	---	---	0.05	0.10
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Total lysine, %	1.55	1.55	1.55	1.55
True digestible amino acids				
Lysine	1.41	1.41	1.41	1.41
Isoleucine:lysine ratio, %	60	60	60	60
Leucine:lysine ratio, %	122	122	122	122
Methionine:lysine ratio, %	32	32	32	32
Met & cys:lysine ratio, %	56	56	56	56
Threonine:lysine ratio, %	66	66	66	66
Tryptophan:lysine ratio, %	17	17	17	17
Valine:lysine ratio, %	68	68	68	68
ME, kcal/lb	1,493	1,493	1,493	1,493
CP, %	21.9	21.9	21.9	21.9
Ca, %	0.90	0.90	0.90	0.90
P, %	0.79	0.79	0.79	0.79
Available P, %	0.50	0.50	0.50	0.50

[a]Fed from d 0 to 14 after weaning.
[b]Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).
[c]Neomycin (100 g/lb Neomycin sulfate).

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

Ingredient, %	Negative Control	Positive Control	Neomycin Sulfate	
			100 g/ton	200 g/ton
Corn	59.27	59.27	59.27	59.27
Soybean meal (46.5% CP)	35.10	35.10	35.10	35.10
Spray dried whey	---	---	---	---
Select menhaden fish meal	---	---	---	---
Soy oil	1.00	1.00	1.00	1.00
Monocalcium P (21% P)	0.50	0.50	0.50	0.50
Limestone	1.10	1.10	1.10	1.10
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.25	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15	0.15
L-threonine	0.15	0.15	0.15	0.15
DL-methionine	0.13	0.13	0.13	0.13
Lysine HCl	0.30	0.30	0.30	0.30
Corn starch	0.70	---	0.65	0.60
Neo-Terramycin® [b]	---	0.70	---	---
Neomycin[c]	---	---	0.05	0.10
Total				
Calculated analysis				
Total lysine, %	1.45	1.45	1.45	1.45
True digestible amino acids				
Lysine	1.31	1.31	1.31	1.31
Isoleucine:lysine ratio, %	62	62	62	62
Leucine:lysine ratio, %	129	129	129	129
Methionine:lysine ratio, %	32	32	32	32
Met & cys:lysine ratio, %	57	57	57	57
Threonine:lysine ratio, %	67	67	67	67
Tryptophan:lysine ratio, %	18	18	18	18
Valine:lysine ratio, %	71	71	71	71
ME, kcal/lb	1,494	1,494	1,494	1,494
CP, %	21.4	21.4	21.4	21.4
Ca, %	0.83	0.83	0.83	0.83
P, %	0.72	0.72	0.72	0.72
Available P, %	0.39	0.39	0.39	0.39

[a]Fed from d 14 to 24 after weaning.
[b]Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).
[c]Neomycin (100 g/lb Neomycin sulfate).

Table 3. Growth Performance of Early-weaned Nursery Pigs Provided Neomycin Sulfate in the Water and Feed[a]

									Probability, P<												
			Neomycin Sulfate mg/L Water			Neomycin Sulfate, g/ton eed			Neg control vs.			Pos control vs.			Combo vs.	Feed Med vs.					
Item	Neg Con	Pos Con[b]	38.0	75.5	113.5	100	200	Combo[c]	Pos Con	Water Med	Feed Med	Water Med	Feed Med	Combo	Water Neo 75.5	Water med	Water med Lin	Water med Quad	Feed med Lin	Feed med Quad	SE
d 0 to 14																					
ADG, lb	0.60	0.67	0.71	0.69	0.70	0.68	0.71	0.75	0.08	0.01	0.01	0.39	0.52	0.07	0.17	0.83	0.03	0.09	0.01	0.41	0.029
ADFI, lb	0.72	0.78	0.80	0.79	0.82	0.81	0.82	0.85	0.15	0.01	0.01	0.38	0.27	0.06	0.13	0.70	0.03	0.31	0.02	0.25	0.032
F/G	1.20	1.16	1.14	1.14	1.17	1.20	1.17	1.14	0.27	0.11	0.52	0.79	0.53	0.68	0.98	0.24	0.44	0.11	0.37	0.80	0.036
d 14 to 24																					
ADG, lb	1.10	1.20	1.20	1.15	1.19	1.22	1.25	1.24	0.08	0.08	0.01	0.65	0.46	0.49	0.13	0.12	0.22	0.41	0.01	0.36	0.041
ADFI, lb	1.56	1.66	1.66	1.60	1.64	1.68	1.68	1.75	0.06	0.08	0.01	0.57	0.63	0.08	0.01	0.17	0.28	0.42	0.02	0.21	0.046
F/G	1.43	1.39	1.40	1.39	1.39	1.38	1.35	1.42	0.30	0.26	0.10	0.90	0.61	0.48	0.50	0.41	0.32	0.56	0.07	0.81	0.030
d 0 to 24																					
ADG, lb	0.81	0.89	0.91	0.89	0.90	0.91	0.93	0.95	0.02	0.01	0.01	0.78	0.36	0.09	0.06	0.38	0.03	0.09	0.01	0.24	0.027
ADFI, lb	1.07	1.14	1.16	1.13	1.16	1.17	1.18	1.23	0.05	0.01	0.01	0.83	0.35	0.04	0.02	0.33	0.05	0.27	0.01	0.16	0.035
F/G	1.33	1.28	1.27	1.27	1.29	1.29	1.26	1.29	0.11	0.03	0.05	0.84	0.89	0.85	0.61	0.96	0.16	0.09	0.03	0.96	0.020

[a]A total of 360 weanling pigs, initially 14.1 lb and 21 ± 3 d of age (PIC L337 × C22). Values are the mean of 9 replications.
[b]Containing Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).
[c]Containing Neomycin sulfate in the water (75.5 mg/L) and Neo-Terramycin® in the feed (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).

Table 4. Water Disappearance of Early-weaned Pigs Provided Water-based Medication (% BW)[a]

		Neomycin Sulfate, mg/L Water			Overall
Item	Control	38.0	75.5	113.5	Mean
d 0 to 7	14.7	19.8	21.0	29.0	21.1
d 7 to 14	19.6	25.5	29.3	31.3	26.4
d 14 to 24	18.5	19.7	25.1	21.7	21.2
d 0 to 24	17.6	21.7	25.1	27.4	22.9

[a]A total of 360 weanling pigs, initially 14.1 lb and 21 ± 3 d of age (PIC L337 × C22). Each value is the mean of 2 replications.

EFFECTS OF INTERMITTENT USAGE OF WATER-BASED NEOMYCIN SULFATE ON THE GROWTH PERFORMANCE OF WEANLING PIGS

R. O. Gottlob, M. D. Tokach, S. S. Dritz[1], R. D. Goodband, J. M. DeRouchey, J. L. Nelssen, C. R. Neill, C. N. Groesbeck, K. R. Brown, and N. Z. Frantz

Summary

A total of 360 weanling pigs (initially 11.4 lb and 18 ± 3 d of age, PIC) were used to determine the effects of intermittent use of water-based medication on nursery pig growth performance. Pigs were given one of eight experimental treatments: negative control (no antibiotics in the feed or water); positive control with Neo-Terramycin® in the feed (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl); continuous use of either 38.0 or 75.5 mg Neomycin sulfate per L of water; use of either 38.0 or 75.5 mg of Neomycin sulfate per L of water, during weeks 1 and 3 after weaning; and use of either 38.0 or 75.5 mg Neomycin sulfate per L of water during weeks 2 and 4 after weaning. Overall (d 0 to 28 after weaning), pigs provided Neomycin sulfate in the water continuously and pigs fed the positive control diet had greater ADG ($P<0.05$) and ADFI ($P<0.04$) than did pigs provided non-medicated water and feed. Pigs fed the positive control diet tended ($P<0.15$) to have greater ADG than did pigs provided an intermittent supply of water-based Neomycin sulfate, but there was no difference in growth performance and feed efficiency between pigs fed the positive control diet and those provided a continuous supply of water-based Neomycin sulfate. Pigs provided a continuous supply of either dosage of Neomycin sulfate in the water had greater ($P<0.05$) ADG and ADFI than did pigs provided water-based Neomycin sulfate on an intermittent basis. These data demonstrate that providing neomycin in the feed or water results in a growth response, but there is no carryover effect. Thus, pig performance returns to the control level immediately after the supply of Neomycin is removed.

(Key Words: Nursery Pig, Antibiotics, Water, Growth.)

Introduction

Recent research conducted at Kansas State University SEW facility showed that the use of water-based medication for nursery pigs improved growth performance, compared with that of pigs fed non-medicated feed and water. The majority of the response occurred at the lowest dosage level. Because of concern for medication cost and the amount of antimicrobial delivered to the pig, intermittent use of water-based medication could be a viable alternative to continuous dosage. If weanling pigs could be provided water-based Neomycin during alternating weeks of the nursery phase without sacrificing growth performance, producers could greatly save on the cost of medication delivery and reduce the total amount of antimicrobial delivered to the pig. Therefore, the objective of this experiment was to determine the effects of intermittent usage of wa-

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

ter-based Neomycin on the growth performance of weanling pigs.

Procedures

A total of 360 weanling pigs (initially 11.4 lb and 18 ± 3 d of age, PIC) were blocked by initial weight, and were randomly allotted to one of eight dietary and/or water treatments. Individual pens were the experimental units and water was supplied by an individual line and bowl waterer in each pen. There were 5 pigs per pen and 9 pens per treatment. Pigs remained on the same treatments for 28 d after weaning. There were eight experimental treatments: negative control (no antibiotics in the feed or water); positive control with Neo-Terramycin® in the feed (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl); continuous use of either 38.0 or 75.5 mg Neomycin sulfate per L of water; use of either 38.0 or 75.5 mg of Neomycin sulfate per L of water during weeks 1 and 3 after weaning; and use of either 38.0 or 75.5 mg Neomycin sulfate per L of water during weeks 2 and 4 after weaning. When used, 19.0 or 37.8 ml of Neomycin liquid (200 mg/ml Neomycin sulfate) was provided per L of water. This provided 38.0 or 75.5 mg of Neomycin sulfate per L of water. Pigs that received water-based antibiotics were fed the negative control diet that did not contain an antibiotic.

Water-based medication was administered through SelectDoser™ peristaltic pumps (Genesis Instruments; Elmwood, WI). This type of doser is powered by electricity, and siphons a concentrated, pre-mixed stock solution through a tube and doses the medication into the existing water supply. Concentrated stock solutions were made once every two days throughout the experiment. Each concentrated solution consisted of 220.0 g citric acid (as a water-line cleaner and drug solubility aid) and 4 L of water with either 76 or 151 ml Neomycin liquid. Pigs not receiving water-based medication were administered a control water treatment only containing citric acid. These concentrated stock solutions were dosed into the existing water line at a ratio of 1:100 to achieve the desired dosage of medication.

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 0.50% available phosphorus. Phase 2 (d 14 to 28 after weaning) diets were formulated to contain 1.31% TID lysine, 0.83% Ca, and 0.39% available phosphorus. The trial was conducted in an environmentally controlled segregated early-weaning nursery facility at Kansas State University. Each pen was 5 × 5 ft and contained one self-feeder and one bowl waterer to provide *ad libitum* access to feed and water. Average daily gain, ADFI, and F/G were determined by weighing pigs and feeders on d 7, 14, 21, and 28 after weaning. In addition, water disappearance was measured. 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 after weaning, the mean of pigs provided continuous water-based Neomycin sulfate had greater ($P<0.02$) ADFI and tended ($P<0.12$) to have greater ADG than did pigs provided non-medicated water and feed. There were no differences in growth performance between pigs provided continuous water-based Neomycin sulfate and those provided the positive control diet and non-medicated water, but, compared with the mean of pigs provided Neomycin sulfate intermittently, those provided medication continuously had greater ($P<0.03$) ADFI and tended ($P<0.06$) to have greater ADG.

From d 7 to 14, the mean of pigs provided continuous water-based Neomycin sulfate had greater (P<0.02) ADG and tended (P<0.07) to have greater ADFI than did pigs provided non-medicated water and feed. The mean of pigs provided water-based Neomycin sulfate on a continuous basis had greater (P<0.01) ADG and tended to have improved (P<0.07) ADFI, compared with the mean of pigs provided medication intermittently.

From d 14 to 21, pigs provided either continuous or intermittent water-based Neomycin sulfate and pigs provided the positive control diet with non-medicated water had greater ADG (P<0.01) and ADFI (P<0.02) than did pigs provided non-medicated water and feed. Pigs provided the positive control diet with non-medicated water also had greater (P<0.05) ADG than did the mean of pigs provided intermittent water-based medication. Pigs provided a continuous supply of water-based Neomycin sulfate had greater (P<0.01) ADG and tended (P<0.08) to have greater ADFI than did the mean of pigs provided medication intermittently.

From d 21 to 28, the mean of pigs continuously provided water-based Neomycin sulfate had poorer (P<0.01) F/G than did pigs provided non-medicated water and feed. Furthermore, pigs intermittently provided water-based Neomycin sulfate had improved (P<0.02) F/G, compared with that of pigs provided the same dosage of medication continuously.

Overall (d 0 to 28 after weaning), pigs provided Neomycin sulfate in the water continuously and pigs fed the positive control diet had greater ADG (P<0.05) and ADFI (P<0.04) than did pigs provided non-medicated water and feed. In addition, pigs fed the positive control diet tended (P<0.15) to have greater ADG than did pigs provided an intermittent supply of water-based Neomycin sulfate. There was no difference, however, in growth performance and feed efficiency between pigs fed the positive control diet and those provided a continuous supply of water-based Neomycin sulfate. Pigs provided a continuous supply of water-based Neomycin sulfate had greater ADG (P<0.02) and ADFI (P<0.04), compared with that of pigs provided water-based Neomycin sulfate on an intermittent basis.

Economic analysis was performed on all treatments and data calculated included: antimicrobial cost per pig (d 0 to 28), feed- and water-based antimicrobial (if applicable) cost per pound of gain, margin over feed and water-based antimicrobial (if applicable). Overall (d 0 to 28), pigs provided either continuous or intermittent water-based Neomycin sulfate and pigs provided the positive control diet and non-medicated water had a greater (P<0.03) antimicrobial cost per pig and cost per pound of gain than did pigs provided non-medicated feed and water. Pigs provided either continuous or intermittent water-based Neomycin sulfate also had greater (P<0.01) antimicrobial cost per pig and cost per pound of gain than did pigs provided the positive control diet and non-medicated water. Among pigs provided water-based medication, pigs provided Neomycin sulfate continuously had a greater (P<0.01) antimicrobial cost per pig and cost per pound of gain than did those provided medication intermittently.

For margin over feed and antimicrobial costs, pigs provided the positive control diet and non-medicated water had a greater (P<0.04) margin than did pigs provided intermittent water-based Neomycin sulfate and non-medicated feed; the margin for pigs provided continuous water-based Neomycin sulfate was intermediate. Although there was no significant difference for margin over feed and antimicrobial costs between pigs fed the positive control diet and those provided the nega-

tive control or continuous water-based medication, numerical differences were observed. Pigs provided non-medicated water and feed had a $0.40 lower margin over feed and antimicrobial cost per pig, whereas pigs provided water-based Neomycin sulfate at 38.0 and 75.5 mg/L had $0.24 and $0.39 lower margin over feed and antimicrobial costs per pig, respectively, than did pigs fed the positive control diet.

In this experiment, water disappearance was slightly less than expected, but followed similar trends in relation to the age of the pigs. In terms of percentage of BW, water disappearance was 15.11% from d 0 to 7. This rate increased slightly during Week 2 of the experiment, but then decreased to 11.36% during Week 4. The overall (d 0 to 28) average water disappearance for the experiment was 14.35% of BW. When expressed as liters per day, however, there is a steady increase in the volumetric disappearance of water as the pigs get older (Table 4).

During the first week of the experiment, water disappearance was 1.98 L/d. This steadily increased to 4.26 L/d by Week 4 of the trial. The overall (d 0 to 28) average water disappearance was 3.32 L/d. Figure 1 shows the increase in water disappearance with the increase in age of the early-weaned nursery pig.

In conclusion, intermittent use of Neomycin sulfate in the water decreased growth performance, compared with that of pigs provided Neomycin sulfate continuously. This indicates that there must be a continual supply of antimicrobials to the nursery pig to optimize growth performance. In addition, antimicrobial cost per pig and feed plus antimicrobial cost per pound of gain is increased by using water as the mode of medication delivery. Margin over feed plus antimicrobial cost is significantly reduced by providing water-based medication to pigs intermittently, whereas only a numerical decrease, lacking significance, was observed with pigs provided water-based medication continuously. The improvement in nursery pig growth performance and resulting increased revenue per pig as a result of continuous feed- or water-based medication offsets the increased cost, compared with results from intermittent use. Further research is needed to determine the lowest dosage of growth-promoting antimicrobial that can be used without sacrificing health and performance, and thus profit. In addition, further research is needed to more accurately quantify the water disappearance and actual water intake of nursery pigs.

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

Ingredient, %	Negative Control	Positive Control
Corn	51.11	51.11
Soybean meal (46.5% CP)	30.16	30.16
Spray dried whey	10.00	10.00
Select menhaden fish meal	3.75	3.75
Soy oil	1.00	1.00
Monocalcium P (21% P)	1.20	1.20
Limestone	0.75	0.75
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-threonine	0.15	0.15
DL-methionine	0.13	0.13
L-lysine HCl	0.30	0.30
Corn starch	0.70	---
Neo-Terramycin® [b]	---	0.70
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.55	1.55
True digestible amino acids		
Lysine, %	1.41	1.41
Isoleucine:lysine ratio, %	60	60
Leucine:lysine ratio, %	122	122
Methionine:lysine ratio, %	32	32
Met & cys:lysine ratio, %	56	56
Threonine:lysine ratio, %	66	66
Tryptophan:lysine ratio, %	17	17
Valine:lysine ratio, %	68	68
ME, kcal/lb	1,493	1,493
CP, %	21.9	21.9
Ca, %	0.90	0.90
P, %	0.79	0.79
Available P, %	0.50	0.50

[a]Fed from d 0 to 14 after weaning.
[b]Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).

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

Ingredient, %	Negative Control	Positive Control
Corn	59.27	59.27
Soybean meal (46.5% CP)	35.10	35.10
Spray dried whey	---	---
Select menhaden fish meal	---	---
Soy oil	1.00	1.00
Monocalcium P (21% P)	0.50	0.50
Limestone	1.10	1.10
Salt	0.35	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
L-threonine	0.15	0.15
DL-methionine	0.13	0.13
L-lysine HCl	0.30	0.30
Corn starch	0.70	---
Neo-Terramycin® [b]	---	0.70
Total		
Calculated analysis		
Total lysine, %	1.45	1.45
True digestible amino acids		
Lysine, %	1.31	1.31
Isoleucine:lysine ratio, %	62	62
Leucine:lysine ratio, %	129	129
Methionine:lysine ratio, %	32	32
Met & cys:lysine ratio, %	57	57
Threonine:lysine ratio, %	67	67
Tryptophan:lysine ratio, %	18	18
Valine:lysine ratio, %	71	71
ME, kcal/lb	1,494	1,494
CP, %	21.4	21.4
Ca, %	0.83	0.83
P, %	0.72	0.72
Available P, %	0.39	0.39

[a]Fed from d 14 to 28 after weaning.
[b]Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).

Table 3. Weekly Growth Performance of Early-weaned Nursery Pigs Provided Intermittent Water-based Medication[a]

Item	Neg Con	Pos Con[b]	Neomycin Sulfate (mg/L water)						Probability, P<							
			Continuous		Intermittent					Neg Control vs.		Pos Control vs.			Continuous vs. Intermittent	SE
					Weeks 1/3		Weeks 2/4									
			38.0	75.5	38.0	75.5	38.0	75.5	Trt	Cont[c]	Int[c]	Neg	Cont	Int		
d 0 to 7																
ADG, lb	0.46	0.51	0.49	0.54	0.49	0.52	0.43	0.45	0.05	0.12	0.81	0.20	0.95	0.16	0.06	0.035
ADFI, lb	0.50	0.53	0.54	0.59	0.52	0.53	0.50	0.54	0.14	0.02	0.38	0.30	0.23	0.66	0.03	0.031
F/G	1.12	1.05	1.12	1.10	1.06	1.02	1.18	1.20	0.02	0.92	0.99	0.24	0.21	0.14	0.88	0.052
d 7 to 14																
ADG, lb	0.84	0.88	0.92	0.95	0.80	0.80	0.94	0.90	0.01	0.02	0.59	0.38	0.16	0.57	0.01	0.043
ADFI, lb	1.00	1.07	1.06	1.10	1.00	1.01	1.06	1.06	0.42	0.07	0.38	0.20	0.71	0.45	0.14	0.053
F/G	1.18	1.21	1.16	1.16	1.24	1.27	1.13	1.18	0.01	0.54	0.45	0.40	0.12	0.77	0.07	0.037
d 14 to 21																
ADG, lb	0.88	1.05	1.00	1.10	1.03	1.09	0.83	0.94	0.01	0.01	0.01	0.01	0.97	0.05	0.01	0.046
ADFI, lb	1.23	1.43	1.38	1.50	1.40	1.38	1.29	1.38	0.02	0.01	0.02	0.01	0.90	0.20	0.08	0.069
F/G	1.41	1.37	1.38	1.36	1.37	1.27	1.55	1.46	0.01	0.44	0.94	0.48	0.96	0.34	0.25	0.058
d 21 to 28																
ADG, lb	1.20	1.16	1.19	1.11	1.10	1.08	1.24	1.25	0.01	0.22	0.39	0.44	0.73	0.89	0.52	0.045
ADFI, lb	1.63	1.66	1.67	1.68	1.58	1.56	1.65	1.73	0.06	0.33	0.99	0.56	0.76	0.46	0.18	0.052
F/G	1.37	1.43	1.42	1.52	1.45	1.44	1.34	1.39	0.01	0.01	0.23	0.12	0.31	0.42	0.02	0.040
d 0 to 28																
ADG, lb	0.84	0.90	0.90	0.92	0.85	0.87	0.86	0.89	0.09	0.01	0.28	0.05	0.66	0.15	0.02	0.028
ADFI, lb	1.09	1.17	1.16	1.22	1.13	1.12	1.13	1.18	0.06	0.01	0.13	0.04	0.61	0.26	0.04	0.040
F/G	1.29	1.30	1.30	1.32	1.31	1.28	1.31	1.33	0.74	0.48	0.43	0.69	0.81	0.77	0.98	0.026

Table 3. (continued)

Antimicrobial Cost/pig[d]	$0.000	$0.145	$0.353	$0.700	$0.176	$0.350	$0.176	$0.350	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.002
Feed + Water Cost/lb of gain[e]	$0.108	$0.114	$0.123	$0.137	$0.117	$0.122	$0.117	$0.125	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.002
Margin Over Feed & Water[f]	$7.44	$7.84	$7.60	$7.45	$7.37	$7.40	$7.42	$7.44	0.64	0.70	0.87	0.12	0.16	0.04	0.46	0.258

[a]A total of 360 weanling pigs, initially 11.4 lb and 18 ± 3 d of age (PIC L337 × C22). Values are the mean of 9 replications.
[b]Containing Neo-Terramycin® (140 g/ton Neomycin sulfate, 140 g/ton Oxytetracycline HCl).
[c]Cont refers to continuous use and Int refers to intermittent use.
[d]Includes antimicrobials in the feed or water consumed over the 28-d experimental period. Based on water-based Neomycin sulfate solution (200mg/ml) cost of $72.95/gal., and feed-grade Neo-Terramycin (10 g/lb Neomycin sulfate, 10 g Oxytetracycline/lb) cost of $0.63/lb
[e]Includes the cost of applicable water-based Neomycin sulfate solution and feed cost over the 28-d experimental period. Based on a negative-control feed cost of $206.64/ton and a positive-control feed cost of $214.34/ton.
[f]Based on current market price of $42.50/cwt. Calculated as gain × $42.50/cwt minus feed and antimicrobial cost per pig.

Table 4. Water Disappearance of Early-weaned Nursery Pigs[a]

Item	% Body Weight	Liters/day
d 0 to 7	15.11	1.98
d 7 to 14	16.08	3.35
d 14 to 21	14.84	3.69
d 21 to 28	11.36	4.26
d 0 to 28	14.35	3.32

[a]A total of 360 weanling pigs, initially 11.4 lb and 18 ± 3 d of age (PIC L337 × C22). Each value is the mean of 2 replications.

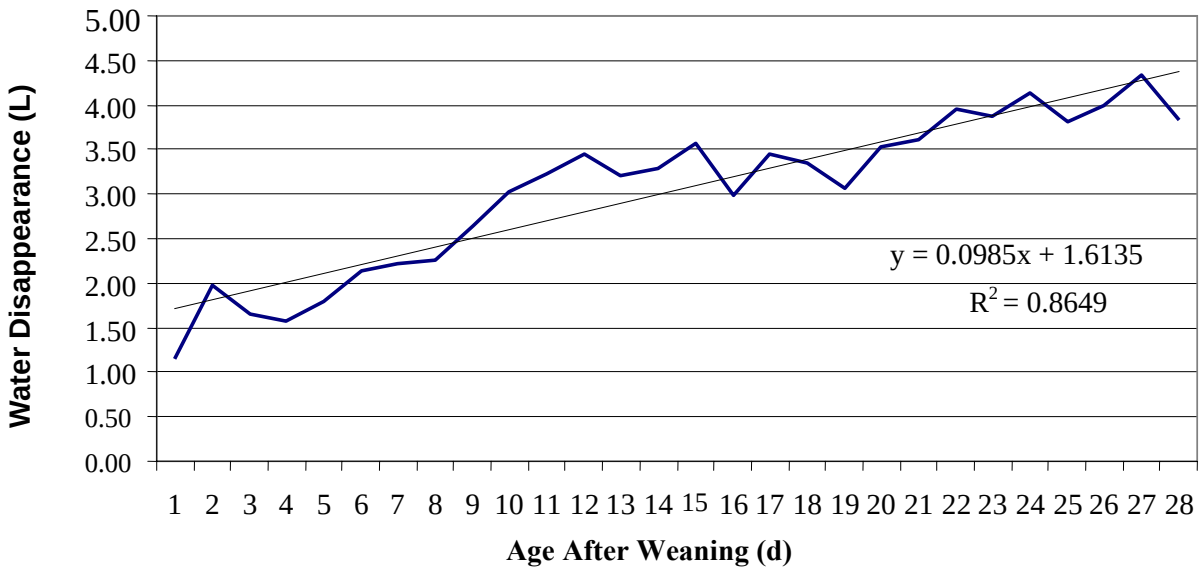


Figure 1. Volumetric Water Disappearance of Early-weaned Nursery Pigs. A total of 360 weanling pigs, initially 11.4 lb and 18 ± 3 d of age (PIC L337 × C22). Each value is the mean of 2 replications.

EFFECTS OF WATER-BASED CITRIC ACID ON GROWTH PERFORMANCE AND WATER DISAPPEARANCE OF WEANLING PIGS

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

Summary

A total of 399 weanling pigs (initially 12.2 lb and 14 ± 3 d of age, PIC) were used to determine the effects of water-based citric acid on nursery pig growth performance and water disappearance. Pigs were given a common diet and one of two experimental water treatments: 1) negative control, water containing no additives; and 2) water containing 0.55 g per L citric acid. Overall (d 0 to 10 after weaning), there were no differences in growth performance between pigs provided water or water with added citric acid. In addition, water disappearance was similar between treatments for the overall period. These results suggest that adding 0.55 g/L of citric acid improves neither pig growth or water intake when offered immediately after weaning.

(Key Words: Citric Acid, Nursery Pig, Water, Growth.)

Introduction

The use of acidifiers in weanling pig nutrition has been shown to improve growth rate and feed efficiency for diets based on corn-soybean meal. Citric acid is a common organic acid included in some diets for this reason. Citric acid added to the drinking water supply is thought to improve water-based antibiotic solubility and improve water intake by the weanling pig. Recent experiments at Kansas State University have shown beneficial growth performance as a result of using water-based antibiotics in place of feed-grade antibiotics. In those experiments, there were difficulties experienced with solubility of the medication in water, and with plugged waterers. Because of the known solubility of citric acid, and its potential for growth promotion, it is of interest for use in water medication dosing systems. Therefore, the objective of this experiment was to determine the effects of water-based citric acid on the growth performance and water disappearance of weanling pigs. This is important to determine if positive results in previous studies evaluating water-based feed medication were due to the specific medication and/or the citric acid added to the water.

Procedures

A total of 399 weanling pigs (initially 12.2 lb and 14 ± 3 d of age, PIC) were blocked by initial weight and randomly allotted to one of two water treatments. Groups of ten pens were supplied by the same water line and served as one experimental unit. There were five pigs per pen and four experimental units (40 pens) per treatment. Pigs remained on the same treatments for 10 d after weaning.

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

The two experimental treatments were negative control and water containing 0.55 g/L citric acid. When used, granular citric acid (Univar USA, LLC; Kirkland, WA) was provided as a concentrate of 55.0 g per L of water, and the concentrate was diluted to a concentrate:water ratio of 1:100. This provided 0.55 g of citric acid per L of drinking water. All pigs received a common diet containing an antibiotic.

Water disappearance data was collected and water treatments were administered through SelectDoser™ peristaltic pumps (Genesis Instruments; Elmwood, WI). This type of doser is powered by electricity; siphons a concentrated, pre-mixed stock solution through a tube; and doses the medication into the existing water supply. Concentrated stock solutions were made once every two days throughout the experiment. The acidified water solution consisted of 4 L of water and 220 g granular citric acid. These concentrated stock solutions were dosed into the existing water line at a ratio of 1:100 to achieve the desired level of acidification.

Phase 1 (d 0 to 5 after weaning) diets (Table 1) were fed in pellet form and were formulated to contain 1.51% true ileal digestible (TID) lysine, 0.79% Ca, and 0.55% available phosphorus. Phase 2 (d 5 to 10 after weaning) diets were formulated to contain 1.40% TID lysine, 0.85% Ca, and 0.48% available phosphorus. The trial was conducted in an environmentally controlled segregated early-weaning nursery facility at Kansas State University. 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, ADFI, and F/G were determined by weighing pigs and feeders on d 5 and 10 after weaning. In addition, water disappearance was measured. Growth performance data were analyzed as a randomized complete-block design, with pair of pens as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS.

Results and Discussion

There were no differences in growth performance between pigs provided the two treatments during Phase 1 (d 0 to 5), Phase 2 (d 5 to 10) or the overall (d 0 to 10) treatment period (Table 2). In addition, water disappearance was similar between treatments for the overall period (Table 3). This indicates that citric acid in the water at 0.55 g/L does not affect pig growth, feed intake, feed efficiency, or water disappearance. Although citric acid is still a valuable water additive to influence antimicrobial solubility, citric acid addition in this experiment did not influence growth performance or water intake. Further research is encouraged with other organic acids to determine potential effects of acidified drinking water on the feed and water disappearance of weanling pigs.

Table 1. Diet Composition (As-fed Basis)

Ingredient, %	Phase 1[a]	Phase 2[b]
Corn	37.14	54.44
Soybean meal (46.5% CP)	20.06	24.51
Spray-dried animal plasma	2.50	---
Select menhaden fish meal	5.00	4.00
Spray-dried blood cells	1.25	---
Spray dried whey	25.00	10.00
Choice white grease	5.00	---
Soy oil	---	3.00
Monocalcium P (21% P)	0.70	1.10
Limestone	0.45	0.70
Salt	0.30	0.30
Zinc oxide	0.38	0.25
Vitamin premix with phytase	0.25	0.25
Trace mineral premix	0.15	0.15
Lysine HCl	0.26	0.30
DL-methionine	0.18	0.18
L-threonine	0.13	0.13
Neo-Terramycin®	1.00	0.70
Acidifier	0.20	---
Vitamin E, 20,000 IU	0.05	---
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.65	1.54
True ileal digestible lysine,%	1.51	1.40
ME, kcal/lb	1,575	1,534
CP, %	22.6	19.8
Ca, %	0.79	0.85
P, %	0.73	0.75
Available P, %	0.55	0.48

[a]Fed from d 0 to 5 after weaning.
[b]Fed from d 5 to 10 fter weaning.

Table 2. Growth Performance of Nursery Pigs Provided Citric Acid in Drinking Water[a]

Item	Control	Citric acid, 0.55 g/L Water	Probability, P< Treatment	SE
d 0 to 5				
ADG, lb	0.52	0.52	0.90	0.019
ADFI, lb	0.43	0.42	0.54	0.016
F/G	0.84	0.83	0.77	0.016
d 5 to 10				
ADG, lb	0.65	0.62	0.20	0.027
ADFI, lb	0.93	0.91	0.35	0.024
F/G	1.48	1.50	0.54	0.034
d 0 to 10				
ADG, lb	0.58	0.57	0.38	0.021
ADFI, lb	0.68	0.67	0.36	0.019
F/G	1.18	1.18	0.98	0.019

[a]A total of 399 weanling pigs, (PIC L337 × C22) initially 12.2 lb. Values are the mean of 40 replications (pens).

Table 3. Water Disappearance of Nursery Pigs Provided Citric Acid in Drinking Water[a]

	% of Body Weight		Liters per Day	
Item	Control	Citric /acid, 0.55 g/L	Control	Citric Acid, 0.55 g/L
d 0 to 5	23.85	23.16	1.64	1.59
d 5 to 10	19.04	18.82	1.60	1.56

[a]A total of 399 weanling pigs, (PIC L337 × C22) initially 12.2 lb. Values are the mean of 4 replications.

EFFECTS OF INCREASING OREGANO OIL ON NURSERY PIG PERFORMANCE

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

Summary

A total of 210 nursery pigs (PIC L327 × L42), with an initial weight of 11.9 lb and 21 d of age, were used in a 28-d growth study. The objective was to evaluate the effects of increasing oregano oil in diets for nursery pigs. Oregano oil is an extract derived from the Greek herb, *Origanum vulgare,* and has been speculated to have antimicrobial-like activity. Previous research at Kansas State University showed no improvement in growth performance in nursery pigs fed oregano oil (0.10% in the Phase 1 diet, and 0.05% in Phase 2). The present study evaluated growth performance of pigs fed diets containing either 0.05%, 0.10%, or 0.20% oregano oil for the entire 28-d study. There was no improvement in ADG, ADFI, F/G, or d-28 weights of pigs fed diets containing oregano oil, compared with performance of pigs fed the control diets. Also, there was no effect ($P>0.15$) of increasing the amount of oregano oil in the diet. But pigs fed neomycin-oxytetracycline had improved ADG, ADFI, and F/G ($P<0.03$), compared with those of pigs fed the control and oregano oil treatments, from d 0 to 14. Overall, (d 0 to 28), pigs fed neomycin-oxytetracycline had better ADG and ADFI ($P<0.006$) than the pigs fed the control diet had, and better ADG, ADFI, F/G, and final body weight ($P<0.04$) than pigs fed the oregano oil treatment had.

(Key Words: Antibiotics, Nursery, Oregano Oil, Pigs.)

Introduction

With more strict regulations on antibiotics in Europe, many swine producers in the United States are concerned about the potential of new restrictions banning feed-grade antibiotics. Several alternative ingredients have been proposed to partly or fully replace antibiotics in swine diets, such as egg immunoglobulins, mannan oligosaccharide, probiotics, fructo-oligosaccharide, spices, botanicals, essential oils, and herbs. But there is either limited or highly variable data to suggest that any of them can successfully replace antibiotics for growth performance. Oregano oil is a plant extract derived from the Greek herb, *Origanum vulgare*. Oregano is a perennial herb that is located in many countries, primarily Greece. Studies in Europe have observed that pigs had improved growth performance, compared with those fed the control diet without antimicrobials, when oregano oil was added to the diet. In a previous study conducted at Kansas State University, no improvement in nursery pig growth performance with oregano oil was found. In that study, pigs were fed oregano oil at 0.10% of the diet in Phase 1 (d 0 to 14) and 0.05% for Phase 2 (d 14 to 28). Oregano oil (5%) is mixed with an

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

inert carrier (95%) to form the premix that is added to the diet. Because we observed no response at this dosage, we speculated that different dosages may be needed to achieve a growth response. Therefore, our objective was to determine the effects of increasing amounts of oregano oil in nursery pig diets.

Procedures

A total of 210 nursery pigs (PIC L327 × L42), with an initial weight of 11.9 lb and 21 d of age, were used in a 28-d growth study. Pigs were blocked by initial weight and sex, and were randomly allotted to one of five dietary treatments in a randomized complete-block design. Each pen contained seven pigs, with either four barrows and three gilts or three barrows and four gilts. There were six replications (pens) per treatment, with a total of 30 pens. Each pen (4 ft × 5 ft) had one water nipple and a self feeder, with woven wire flooring. This study was conducted at the Kansas State University Swine Research and Teaching Center in an environmentally regulated nursery.

Dietary treatments consisted of a negative control (no antimicrobials or oregano oil), positive control (neomycin sulfate, 140 g/ton and oxytetracycline, 140 g/ton), and three rates of oregano oil (0.05, 0.10, and 0.20%). Experimental diets were fed in meal form and in two phases (Table 1). Phase 1 diets were fed from d 0 to 14; Phase 2 was fed from d 14 to 28. Diets were formulated to contain 1.55% total dietary lysine, 15% whey, and 3.75% fish meal in Phase 1. In the Phase 2 diets, the lysine concentration was formulated to contain 1.45% total dietary lysine, with no specialty protein sources.

In the experimental diets, the antibiotic or the oregano oil was added at the expense of corn starch. Pigs were weighed weekly to determine ADG, ADFI, and F/G. Data were analyzed by using the MIXED procedures of SAS v. 8.1 in a randomized complete-block design. Linear and quadratic polynomial contrasts were performed to determine the effects of increasing oregano oil.

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 P (21% P)	1.15	1.60
Limestone	0.70	1.10
Salt	0.33	0.35
Vitamin premix	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
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 (0.05, 0.10, or 0.20%) or neomycin sulfate (140 g/ton) and oxytetracycline (140 g/ton) was added at the expense of corn starch to provide the experimental diets.

Results and Discussion

From d 0 to 14 (Table 2), pigs fed neomycin-oxytetracycline had improved ADG, ADFI, and F/G, (P<0.03), compared with those of pigs fed the oregano oil or the negative control diet. Overall (d 0 to 28), pigs fed the diet containing neomycin-oxytetracycline

had greater ADG and ADFI (P<0.006) than pigs fed the control diet had. Also, pigs fed neomycin-oxytetracycline had improved ADG, ADFI, F/G, and final body weight, compared with those of pigs fed oregano oil. Increasing amounts of oregano oil did not influence growth performance (P>0.15). Also, pigs fed oregano oil did not differ in performance (P>0.13) from pigs fed the control diet.

In conclusion, when oregano oil was added to the diet at 0.05, 0.10, or 0.20%, there were no improvements in growth performance of nursery pigs. These results, along with the previous research, suggest that oregano oil is not an effective growth-promoting feed additive in nursery pig diets.

Table 2. Effects of Increasing Oregano Oil on Nursery Pig Performance[a]

			Oregano Oil, %				Probability, $P <$[b]	
Item	Control[c]	Neo-Terra[d]	0.05	0.10	0.20	SED	Control vs. Neo-Terra	Neo-Terra vs. Oregano
Initial wt., lb	11.8	11.9	11.9	11.9	11.9	1.252	0.98	0.99
d 0 to 14								
ADG, lb	0.52	0.68	0.50	0.50	0.52	0.036	0.0001	0.0001
ADFI, lb	0.58	0.71	0.55	0.59	0.60	0.038	0.002	0.0003
F/G	1.12	1.04	1.11	1.18	1.16	0.035	0.03	0.001
d 0 to 28								
ADG, lb	0.79	0.92	0.79	0.78	0.79	0.038	0.002	0.0002
ADFI, lb	0.99	1.15	1.00	1.01	1.02	0.051	0.006	0.003
F/G	1.26	1.24	1.28	1.30	1.29	0.020	0.35	0.01
Final wt., lb	33.9	37.7	33.9	33.7	34.0	2.175	0.09	0.04

[a]A total of 210 nursery pigs (PIC L327 × L42) initially 11.9 lb and 21 d of age with seven pigs/pen and six replications (pens)/treatment. A total of 30 pens with either four barrows and three gilts or three barrows and four gilts/pen.
[b]No linear or quadratic oregano oil effects (P>0.15) or control versus oregano oil effects (P>0.13).
[c]Contained no in-feed antimicrobial or oregano oil.
[d]Contained neomycin sulfate (140 g/ton) and oxytetracycline (140 g/ton).

GROWTH PERFORMANCE OF NURSERY PIGS FED BIOSAF[1] YEAST, ALONE OR IN COMBINATION WITH AN IN-FEED ANTIMICROBIAL[2]

B. M. Hildabrand, T. E. Burkey, K. A. Skjolaas-Wilson, S. S. Dritz[3], B.J . Johnson, and J. E. Minton

Summary

A total of 280 pigs were used in a 28-d growth study to evaluate the effects of feeding the antimicrobial carbadox, BIOSAF (0.4%), and the combination of carbadox and BIOSAF yeast (0.15%) in nursery pig diets. Over the length of the entire trial, pigs fed the diet containing carbadox alone had greater ADG than did pigs fed the control diet or the diet containing 0.4% BIOSAF. Overall, pigs fed the diet containing both carbadox and 0.15% BIOSAF had greater ADG than did pigs fed the control diet or the diet containing 0.4% BIOSAF ($P<0.04$), although their growth performance did not differ from that of pigs fed carbadox alone. Antibody titers in response to routine vaccination against *Mycoplasma hyopneumoniae* were not affected by dietary treatment. There was no evidence that BIOSAF improved growth performance of nursery pigs, either alone or in combination with the carbadox. It is possible that the interactive effects of BIOSAF that have been reported for other in-feed antibiotics are not present when BIOSAF is combined with carbadox, or perhaps interactive effects are only observed when carbadox itself exerts a more potent stimulation of ADG in nursery pigs.

(Key Words: Antimicrobials, BIOSAF, Carbadox, Nursery Pig, 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 that of diets without antibiotics when fed in pelleted nursery diets at 0.2% (Kansas State University Swine Day 1998 report). BIOSAF fed at 0.15% in combination with Neo-Terra resulted in greater ADG and ADFI than did a diet without antibiotics, and resulted in numerically greater ADG than that of pigs fed Neo-Terra (Kansas State University Swine Day 2004 report).

---

[1]BIOSAF is a registered trademark of Saf Agri, Minneapolis, MN.

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

[3]Food Animal Health & Management Center, College of Veterinary Medicine.

Procedures

A total of 280 weaned pigs (initial BW 12.48 lbs) were used in a 28-d study to evaluate the effect of BIOSAF yeast, alone and in combination with an antibiotic, on pig growth performance. There were four treatments, with seven pigs per pen and ten pens per treatment. Pigs were blocked by weight and sex, and assigned randomly within block to one of four 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 contain 1.55% total dietary lysine, 15% whey and 3.75% fish meal in from d 0 to 14 after weaning. From d 15 to 28 after weaning, the diets were formulated to contain 1.45% total dietary lysine, with no specialty protein sources. The negative control diet contained no added antibiotic or yeast, and the positive control diet contained the antibiotic carbadox (Mecadox® 50 g/ton). The first test diet contained BIOSAF yeast at 0.4 %, and the second test diet contained the combination of 0.15 % BIOSAF and carbadox. All diets were formulated without growth-promoting rates of copper sulfate or zinc oxide.

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

The day before weaning (d -1), all pigs were vaccinated against *Mycoplasma hyopneumoniae* (*M. hyo*; RESPISURE®). Two pigs were chosen at random from each pen, and received booster vaccinations at d 13. Serum was collected at the conclusion of the experiment (d 27) and forwarded to the Iowa State University Veterinary Diagnostic Laboratory to be assayed for antibodies to *M. hyo* by employing two widely used diagnostic assays. Titer values from the two pigs within pens receiving booster vaccinations were averaged to produce pen mean titers for analysis.

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	---
Menhaden fish meal	5.00	---
Choice white grease	3.00	3.00
Monocalcium P (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	0.13
Total	100.00	100.00

[a]Corn was removed from the basal diet and replaced with carbadox (Mecadox®, PhiBro Animal Health) to provide 50 g/ton and BIOSAF yeast (0.4 %) to achieve the experimental diets.

Results and Discussion

During the first two weeks of the experiment (d 0 to 14 after weaning), no differences were detected for ADG, ADFI, or F/G among the four diets (Table 2). During the last two weeks (d 15 to 28 after weaning), pigs fed the diet containing carbadox, with and without BIOSAF, had greater ($P<0.04$) ADG and ADFI than did pigs fed the diet containing 0.4% BIOSAF. There were no differences detected in F/G during the final two weeks.

Overall (d 0 to 28), pigs fed the diet containing carbadox, with and without BIOSAF,

had greater (P<0.03) ADG than did pigs fed the diet containing 0.4% BIOSAF, and pigs fed carbadox alone had greater ADG (P<0.03) than did control pigs. Pigs fed the diet containing carbadox and BIOSAF 0.15% had a greater ADFI than did pigs fed either the control diet or 0.4% BIOSAF (P<0.04). There was no difference in F/G among the four diets for the overall trial. Antibody titers to *M. hyo* were not affected by dietary treatment, regardless of the assay used (Table 2).

There was no evidence that BIOSAF improved growth performance of nursery pigs, either alone or in combination with the carbadox. It is possible that the interactive effects of BIOSAF that have been reported for other in-feed antibiotics are not present when BIOSAF is combined with carbadox, or perhaps interactive effects are only observed when carbadox itself exerts a more potent stimulation of ADG in nursery pigs.

Table 2. Growth Performance and Serum Titers to *Mycoplasma hyopneumoniae* (*M. hyo*) Vaccination[a]

	Dietary Treatment[b]					
	Control	Carbadox	BIOSAF 0.4 %	Carbadox+ BIOSAF 0.15 %	SE	Probability P <
d 0 to 14						
ADG, lb	0.29	0.34	0.31	0.30	0.02	0.18
ADFI, lb	0.37	0.38	0.37	0.37	0.02	0.94
F/G	1.26	1.12	1.21	1.23	0.04	0.30
d 15 to 28						
ADG, lb	1.11[c,d]	1.16[c]	1.07[d]	1.16[c]	0.03	0.01
ADFI, lb	1.30[c]	1.44[d]	1.35[c]	1.46[d]	0.04	0.01
F/G	1.22	1.25	1.27	1.26	0.01	0.07
d 0 to 28						
ADG, lb	0.70[c,d]	0.75[e]	0.69[c]	0.73[d,e]	0.02	0.03
ADFI, lb	0.86[c]	0.91[d]	0.86[c]	0.92[d]	0.03	0.04
F/G	1.22	1.22	1.25	1.25	0.01	0.10
Titer[f]						
IDEXX	0.32	0.46	0.35	0.36	0.05	0.29
Dako, %	40.6	34.3	32.2	29.4	5.8	0.57

[a]A total of 280 pigs (seven pigs per pen and tens per treatment). Titers to *M. hyo* represent serum antibodies present at d 27 to vaccination with RESPISURE® at weaning (d -1) and again at d 13.

[b]Control = diet containing no added antibiotic or yeast; Carbadox = diet with 50 g/ton carbadox; BIOSAF 0.4% = diet with BIOSAF yeast at 0.4%; carbadox+BIOSAF 0.15% = Carbadox diet with BIOSAF at 0.15%.

[c,d,e]Means having different superscript letters within a row differ (P<0.05).

[f]IDEXX and Dako are separate, but widely used, diagnostic assays for pig serum antibodies to *M. hyo*. IDEXX means are expressed as a ratio of sample to positive, and values generally greater than 0.4 are considered positive for antibodies to *M. hyo*. Dako means are expressed as a percentage of absorbance values in negative control wells, with lower percentages corresponding to higher titers. For this assay, values generally less than 50% are considered positive for antibodies to *M. hyo*.

THE EFFECT OF PAYLEAN[1] ON NURSERY PIG PERFORMANCE

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

Summary

A 28-d growth study with a total of 192 weanling pigs (PIC 210 × L42, 21 ± 2 d of age and 14.6 lb initial BW) was conducted to determine the effects on nursery pig performance resulting from feeding Paylean (5 ppm) for 3, 7, or 14 d after weaning. A Phase 1 diet containing 15% spray-dried whey, 3.75% fish meal, and 3% soybean oil was fed to all pigs for the initial 14 d. The diet contained 1.55% lysine, and DL-methionine and L-threonine were added to maintain minimum amino acid ratios. The dietary treatments were formulated with or without Paylean (5 ppm) replacing corn starch. All pigs were fed a Phase 2 diet based on corn and soybean meal, without added specialty ingredients, from d 14 to 28. From d 0 to 3, pigs fed the control diet had increased ADFI ($P<0.05$), compared with those fed Paylean. From d 0 to 7, as duration of Paylean feeding increased, ADG decreased (linear, $P<0.01$) and F/G became poorer (linear, $P<0.01$). Pigs fed Paylean had reduced ADFI ($P<0.04$), compared with that of pigs fed the control diet. From d 0 to 14, as duration of Paylean feeding increased, ADG (linear, $P<0.01$) and ADFI (linear, $P<0.05$) decreased and F/G became poorer (linear, $P<0.01$). There were no differences in ADG, ADFI, or F/G ($P>0.23$) when a common Phase 2 diet was fed from d 14 to 28 after weaning. Overall, d 0 to 28, ADG decreased (linear, $P<0.05$) and F/G became poorer (linear, $P<0.05$) as duration of Paylean feeding increased. Average daily feed intake was unaffected by duration of Paylean feeding ($P>0.13$). In addition, as duration of Paylean feeding increased from 0 to 14 d, ending weights tended to decrease (linear, $P<0.06$). In conclusion, feeding Paylean to nursery pigs after weaning reduced performance, and the reduction was greater the longer it was fed after weaning. Paylean should not be fed to newly weaned nursery pigs.

(Key Words: Paylean, Weanling Pig.)

Introduction

Some consultants recently have reported that feeding Paylean to nursery pigs increases feed intake in newly weaned pigs. The consultants are using Paylean as a tool to help pigs get started eating feed quicker after weaning. Paylean is labeled only for use in finishing pigs and, thus, feeding to nursery pigs would be an off-label use. No scientific evidence exists on this practice. Paylean is a beta-adrenergic agonist that accelerates finishing pig muscle deposition by shifting nutrients toward lean tissue growth.

The objective of our experiment was to determine if feeding Paylean to nursery pigs directly after weaning for various lengths of time could enhance feed intake and, thus, improve nursery pig performance.

[1]Paylean is a registered trademark of Elanco Animal Health, Indianapolis, IN.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.

Procedures

A total of 192 weaned pigs (PIC 210 × L42, initially 14.6 lb and 21 ± 2 d of age) were blocked by weight in a 28-d growth study. Pigs were randomly allotted to one of four durations of Paylean feeding (0, 3, 7, or 14 d) in a randomized complete-block factorial design, with time and diet as the main effects of treatment. Each pen contained six pigs per pen, with eight replicates (pens) per treatment. Pigs were housed at the Kansas State University 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.

Experimental diets were based on corn-soybean meal and were fed in meal form for the 28-d trial. The Phase 1 diet was fed from weaning up to d 14 and contained 1.55% total lysine (Table 1). The treatments consisted of either 5 ppm Paylean or no Paylean fed for 0, 3, 7, or 14 d, with pigs being switched to the control diet after the different Paylean durations. A common Phase 2 was fed from d 14 to 28 and contained 1.45% total lysine (Table 1). Pigs were weighed, and feed disappearance was measured, on d 0, 3, 7, 14, and 28 to determine ADG, ADFI, and feed efficiency (F/G). Data were analyzed as a randomized complete-block design, with pen as the experimental unit using the MIXED procedure of SAS.

Results and Discussion

From d 0 to 3, feeding nursery pigs Paylean did not affect ADG or F/G ($P>0.11$), but pigs fed the control diet had increased ADFI ($P<0.05$), compared with that of pigs fed Paylean. Treatment F/G means were variable due to the inherent variation in pigs starting on feed during the first three days, and were influenced by one or two pens per treatment.

From d 0 to 7, as duration of Paylean feeding increased, ADG decreased (linear, $P<0.01$) and F/G became poorer (linear, $P<0.01$). Pigs fed Paylean also had reduced ADFI ($P<0.04$), compared with that of pigs fed the control diet. From d 0 to 14, as duration of Paylean feeding increased, ADG (linear, $P<0.01$) and ADFI decreased (linear, $P<0.05$), and F/G became poorer (linear, $P<0.01$). From d 14 to 28, in which a common Phase 2 diet was fed, there were no differences in ADG, ADFI, or F/G ($P>0.23$).

For the overall trial (d 0 to 28), as duration of Paylean feeding increased from 0 to 14 d, ADG decreased (linear, $P<0.05$) and F/G became poorer (linear, $P<0.05$). Average daily feed intake was unaffected by length of Paylean feeding ($P>0.13$). In addition, as duration of Paylean feeding increased from 0 to 14 d, ending weights tended to decrease (linear, $P<0.06$).

In conclusion, feeding nursery pigs Paylean decreased pig performance, and the reduction was greater the longer it was fed. We speculate this may be because nursery pigs are in an extremely energy-dependent state for protein deposition already, and Paylean's ability to shift energy toward protein deposition may be limited. After pigs fed Paylean were switched to the control diet there were no changes in pig performance, indicating that there were not any carryover effects from the Paylean feeding. Paylean should not be fed to nursery pigs to enhance growth performance or feed intake directly after weaning.

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

Ingredient, %	Phase 1	Phase 2
Corn	45.77	58.00
Soybean meal (46.5% CP)	29.13	35.21
Spray dried whey	15.00	---
Fish meal	3.75	---
Soybean oil	3.00	3.00
Monocalcium P (21 % P)	1.25	1.40
Vitamins and trace minerals	0.40	0.40
Limestone	0.65	1.05
Salt	0.35	0.35
L-lysine HCl	0.30	0.30
L-threonine	0.18	0.15
DL-methionine	0.20	0.15
Cornstarch[b]	0.03	---
Paylean	---	---
Total	100.00	100.00
Calculated values		
Total lysine, %	1.55	1.45
ME, kcal/lb	1,553	1,560
Ca, %	0.90	0.80
P, %	0.80	0.70

[a]All pigs were fed Phase 1 diet from d 0 to 14 and Phase 2 diet from d 14 to 28 after weaning. Paylean was included in the Phase 1 diet fed for the first 0, 3, 7, or 14 d after weaning. All diets were fed in meal form.
[b]Cornstarch was replaced to provide 5 ppm Paylean.

Table 2. Effect of Feeding Paylean on Nursery Pig Performance[a]

		Paylean (5 ppm)				Probability, P <		
Item	Control	3 d	7 d	14 d	SE	Control vs. Paylean	Linear	Quadratic
d 0 to 3								
ADG, lb	0.36	0.33	0.27	0.28	0.059	0.17	0.11	0.67
ADFI, lb	0.29	0.24	0.25	0.24	0.028	0.05	0.13	0.32
F/G	0.86	0.74	1.56	1.00	0.481	0.55	0.42	0.53
d 0 to 7								
ADG, lb	0.28	0.26	0.22	0.19	0.030	0.03	0.01	0.93
ADFI, lb	0.34	0.28	0.31	0.29	0.024	0.04	0.16	0.30
F/G	1.28	1.12	1.50	1.61	0.121	0.19	0.01	0.14
d 0 to 14								
ADG, lb	0.43	0.39	0.37	0.34	0.028	0.02	0.01	0.74
ADFI, lb	0.49	0.44	0.43	0.44	0.023	0.02	0.05	0.12
F/G	1.17	1.15	1.19	1.31	0.054	0.27	0.01	0.09
d 14 to 28								
ADG, lb	1.18	1.14	1.12	1.11	0.052	0.27	0.23	0.79
ADFI, lb	1.54	1.50	1.50	1.47	0.063	0.31	0.27	0.92
F/G	1.32	1.31	1.34	1.32	0.018	0.62	0.41	0.79
d 0 to 28								
ADG, lb	0.80	0.76	0.75	0.73	0.038	0.09	0.05	0.76
ADFI, lb	1.02	0.97	0.97	0.95	0.040	0.13	0.15	0.58
F/G	1.28	1.27	1.30	1.32	0.020	0.26	0.05	0.54
Weight								
d 0	14.7	14.6	14.6	14.6	0.02	0.13	---	---
d 28	37.1	36.0	35.5	35.0	1.08	0.09	0.06	0.75

[a]Each value is the mean of eight replications with 6 pigs (initially 14.6 lbs of BW) per pen. All pigs were fed the Phase 1 diet from d 0 to 14 and Phase 2 diet from d 14 to 28 after weaning. Paylean was included in the Phase 1 diet fed for the first 0, 3, 7, or 14 d after weaning.

THE EFFECTS OF DIETARY GLUTAMINE, GLYCINE, AND SODIUM CHLORIDE CONCENTRATION ON NURSERY PIG GROWTH PERFORMANCE

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

Summary

We conducted a trial to evaluate the effects of feeding added salt (0.38% in addition to the 0.35% already added to the diet) and a 0.70% addition of a blend of 50% glutamine and 50% glycine to weanling pigs as a substitute for spray-dried animal plasma. A total of 216 pigs (initial BW 12.4 ± 1.9 lb and 21 ± 2 d of age) were used, with six pigs per pen and six pens per treatment. Pigs were randomly allotted to pens, blocked by weight, and assigned to one of the six dietary treatments. The six treatments were a negative control diet based on corn-soybean meal, a positive contol diet containing 5% spray-dried animal plasma, and diets with high concentrations of synthetic amino acids. Diets were arranged in a 2 × 2 factorial, with or without 0.7% of a 50:50 blend of glutamine and glycine and with or without added salt (0.38% more than the basal level of 0.35% in all diets). From d 0 to 7, ADG and ADFI increased (P<0.05) for the pigs fed the positive control diet, compared with all other treatments. Pigs fed the synthetic amino acid diets (glutamine:glycine and Na treatments) had improved (P<0.05) F/G, compared with that of pigs fed the negative and positive control diets. From d 7 to 14, pigs fed the positive control diet had increased ADG, compared with that of the pigs fed the negative control, but ADG did not differ from that of pigs on any of the four glutamine: glycine and Na treatment diets. Pigs fed the positive control diet had greater ADFI and improved F/G for d 7 to 14, compared with those of pigs in all other treatments. For the overall feeding period, (d 0 to 14), pigs fed the positive control diet had a numerical improvement in ADG, compared with that of pigs fed the synthetic amino acid diets. Pigs fed the positive control diet also had a greater (P<0.05) ADG and ADFI than those fed the negative control diet. The pigs fed the positive control diet consistently had greater ADFI than pigs in all other treatments. The increase in ADFI corresponds to the increase in ADG for the overall feeding period. The data suggest that adding spray-dried animal plasma to the diet improves ADFI and ADG, and it seems that synthetic amino acid diets containing added Na and a 0.70% dietary blend of 50:50 glutamine:glycine can not equal the response exhibited when spray-dried animal plasma is added to nursery pig diets. Pigs fed the synthetic amino acid diets did have greater growth performance than that of pigs fed the negative control diet. The addition of large amounts of salt or the glutamine:glycine blend to synthetic amino acid diets did not have any influence on pig performance in this experiment.

(Key Words: Nursery Pig, Glutamine, Glycine, Sodium.)

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

Introduction

The importance of starting pigs on feed is always emphasized to ensure long-term performance. Specialty proteins such as spray-dried animal plasma are added to weanling pig diets to stimulate feed intake. Spray-dried animal plasma is very expensive and, if it could be replaced by an alternate source, there is potential to reduce feed cost. Previous research has demonstrated that glutamine and glycine may aid in gut repair and maturation during the Phase 1 feeding period (d 0 to 14). Research also has demonstrated that increased Na and Cl in the diet can influence feed intake, and may have similar impacts to spray-dried animal plasma. Spray-dried animal plasma has a higher concentration of Na and Cl, as well as increased concentrations of glutamine and glycine, which may be contributing to the growth response demonstrated in pigs fed spray-dried animal plasma. Therefore, we evaluated the growth performance of weanling pigs fed diets in which the spray-dried animal plasma was replaced with high concentrations of synthetic amino acids, and with either added Na, 50:50 glutamine and glycine blend, or both Na and 50:50 glutamine and glycine blend.

Procedures

A total of 216 pigs (initial BW 12.4 ± 1.9 lb and 21 ± 2 d of age), were used in a 14-d growth assay, with 6 pigs per pen and 6 pens per treatment. Pigs were randomly allotted to pens, blocked by weight, and randomly allotted to one of six dietary treatments in a 2 × 2 factorial with a negative and positive control. The negative control was a simple diet based on corn soybean meal; the positive control diet had 5% spray-dried animal plasma added; the plasma replaced soybean meal in the negative control diet. The main effects in the factorial were a 0.70% addition of glutamine and glycine (50:50 glutamine:glycine blend) and added salt (0.38% added in excess of the basal content of 0.35% in all diets). The basal diet for the 2 × 2 factorial contained high concentrations of synthetic amino acids. The synthetic amino acids replaced spray-dried animal plasma to ensure that none of the essential amino acids were limiting. The minimum amino acid:lysine ratios used when adding the synthetic amino acids were 60% for isoleucine, 30% for methionine, 60% for methionine and cysteine, 65% for threonine, 16.5% for tryptophan, and 66% for valine. The high salt concentration was chosen to match the sodium (0.45%) provided by the spray-dried animal plasma in the diet. The 0.7% addition of the 50:50 glutamine:glycine blend was used to provide enough nonessential amino acids to reduce the lysine:CP ratio to 7.0. This treatment structure would allow us to determine whether the nonessential amino acids or sodium content were an important part of the response to spray-dried animal plasma normally found with nursery pigs.

The trial was conducted at the Kansas State Swine Teaching and Research Center. Pigs were housed in an environmentally controlled nursery, in 4 ft × 4 ft pens. Pigs were offered *ad libitum* access to food and water. Pigs and feeders were weighed on d 0, 7, and 14 after weaning to calculate ADG, ADFI, and F/G. Data was analyzed by using Proc MIXED procedures in SAS 8.1. Contrast statements were used to determine the differences between treatments.

Results and Discussion

From d 0 to 7, ADG and ADFI increased ($P<0.05$) for the pigs fed the positive control diet, but pigs fed the synthetic amino acid diets (glutamine:glycine and Na factorial) had an improved ($P<0.05$) F/G, compared with pigs fed the negative and positive control diets. This data is consistent with previous results demonstrating that increasing the

synthetic amino acids in a diet improves F/G. When synthetic amino acids are added to the diet, total soybean meal is reduced, resulting in higher calculated net energy, which may be the reason for the improved F/G. The improvement in F/G corresponded to numerically greater ADG, compared with that from the negative control diet. The numerical improvement in ADG was much less than that achieved by the addition of spray-dried animal plasma in the positive control diet. Diets containing spray-dried animal plasma consistently result in increased ADG corresponding to an increase in feed intake.

From d 7 to 14, pigs fed the positive control diet had improved ADG, compared with those fed the negative control, but they did not differ from pigs fed the synthetic amino acid diets. Pigs fed the synthetic amino acid diets maintained the improved F/G demonstrated from d 0 to 7. Feed efficiency for pigs fed the synthetic amino acid diet was less than for pigs fed the positive control, with pigs fed the negative control being intermediate. Pigs fed the positive control diet had greater ADFI than pigs in all other treatments had.

For the overall feeding period, (d 0 to 14), pigs fed the positive control diet had a numerical improvement in ADG, compared with that of pigs fed the synthetic amino acid diets, and an increase ($P<0.05$) in ADG, compared with that of pigs fed the negative control diet. The pigs fed the positive control diet consistently had greater ($P<0.05$) ADFI than pigs in all other treatments. Similar to the d 0-to-7 and the d 7-to-14 feeding periods, for the overall period, pigs fed the synthetic amino acid diets had improved F/G, compared with that of pigs fed either the negative or positive control diets.

The data suggest that adding spray-dried animal plasma improves ADFI and ADG, and it seems that diets containing high concentrations of synthetic amino acid, whether they contain high concentrations of salt and the glutamine:glycine blend or not, can not equal the response exhibited when adding spray-dried animal plasma to nursery pig diets, but these diets do result in greater growth response than the negative control diet. The addition of high concentrations of salt or the glutamine:glycine blend to the synthetic amino acid diets did not influence pig performance in this experiment.

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

	Control Diets		Added Salt			
			Added Glutamine and Glycine			
Item	Negative	Positive	-	+	-	+
Corn	41.14	48.83	50.89	50.89	50.89	50.89
Soybean meal (46.5% CP)	40.56	27.98	28.02	28.02	28.02	28.02
Monocalcium P (21% P)	1.50	1.20	1.60	1.60	1.60	1.60
Limestone	0.83	1.08	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.73	0.73
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
Sand	---	---	0.38	0.38	---	---
Corn starch	---	---	1.35	---	1.35	---
L-threonine	0.04	0.01	0.23	0.23	0.23	0.23
L-glycine	---	---	---	0.35	---	0.35
Amino Gut® [a]	---	---	---	1.00	---	1.00
L-isoleucine	---	---	0.08	0.08	0.08	0.08
L-valine	---	---	0.09	0.09	0.09	0.09
L-tryptophan	---	---	0.01	0.01	0.01	0.01
L-lysine HCl	0.06	0.06	0.47	0.47	0.47	0.47
DL-methionine	0.13	0.10	0.25	0.25	0.25	0.25
Spray-dried porcine plasma	---	5.00	---	---	---	---
Spray-dried whey	15.00	15.00	15.00	15.00	15.00	15.00
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis						
TID lysine, %	1.35	1.35	1.35	1.35	1.35	1.35
Total lysine, %	1.51	1.50	1.48	1.48	1.48	1.48
Total lysine:protein ratio, %	6.21	6.50	7.34	6.99	7.34	6.99
ME, kcal/lb	1,482	1,496	1,458	1,458	1,459	1,459
Protein, %	24.4	23.0	20.2	21.2	20.2	21.2
Ca, %	0.85	0.86	0.86	0.86	0.86	0.86
P, %	0.82	0.78	0.78	0.78	0.78	0.78
Available P, %	0.50	0.50	0.51	0.51	0.51	0.51
Lysine:calorie, g/Mcal	4.63	4.54	4.61	4.61	4.61	4.61
Sodium, %	0.30	0.45	0.30	0.30	0.45	0.45
Chloride, %	0.48	0.55	0.56	0.56	0.78	0.78
Potassium, %	1.30	1.07	1.06	1.06	1.06	1.06

[a]Amino Gut® (Ajinomoto Heartland, Eddieville, IA) provided the 0.35 % glutamine in the diet.

Table 2. Effect of High Concentrations of Salt and a Glutamine:Glycine Blend on Pig Performance[a]

			Added Salt				
	Control Diets		Added Glutamine and Glycine				
Item	Negative	Positive	-	+	-	+	SE
d 0 to 7							
ADG	0.27[b]	0.41[c]	0.30[b]	0.32[b]	0.33[bc]	0.29[b]	0.02
ADFI	0.36[b]	0.46[c]	0.34[b]	0.37[b]	0.33[b]	0.32[b]	0.03
F/G	1.34[b]	1.14[b]	1.25[b]	1.16[b]	1.02[c]	1.08[c]	0.09
d 7 to 14							
ADG	0.78[b]	0.89[c]	0.86[bc]	0.82[bc]	0.81[bc]	0.82[bc]	0.05
ADFI	0.94[b]	1.14[c]	0.97[b]	0.95[b]	0.95[b]	0.91[b]	0.06
F/G	1.21[bc]	1.28[b]	1.12[c]	1.15[c]	1.19[c]	1.11[c]	0.04
d 0 to 14							
ADG	0.52[b]	0.65[c]	0.58[bc]	0.57[bc]	0.58[bc]	0.56[bc]	0.03
ADFI	0.65[b]	0.80[c]	0.65[b]	0.66[b]	0.64[b]	0.61[b]	0.04
F/G	1.24[b]	1.23[b]	1.13[c]	1.15[c]	1.11[c]	1.11[c]	0.03

[a]A total of 216 pigs (initial BW 12.4 ± 1.9 lb and 21 ± 2 d of age), were used in a 14-d growth assay, with 6 pigs per pen and 6 pens per treatment.
[b,c]Means in same row with different superscripts differ ($P<0.05$) .

EFFECT OF WHEY PROTEIN CONCENTRATE SOURCE ON GROWTH PERFORMANCE OF NURSERY PIGS

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

Summary

A total of 228 weanling pigs (initially 14.7 lb and 21 ± 3 d of age, PIC L210 × L42) were used to evaluate the effects of whey protein concentrate (WPC) source on growth performance of weanling pigs. Pigs were fed one of seven experimental diets: a negative control, with no WPC (control); a positive control, with 5% spray-dried animal plasma (SDAP); or the negative control diet with one of five WPC sources (Sources 1 through 5). 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 28 after weaning. From d 0 to 14, pigs fed diets containing WPC from Source 1 had greater ADG ($P<0.05$) than did pigs fed the control diet or WPC from Source 3. Pigs fed SDAP also had greater ADG and ADFI ($P<0.05$) than did pigs fed WPC from Source 3. Pigs fed WPC tended to have poorer ADFI ($P<0.09$) than that of pigs fed SDAP. All pigs fed WPC diets had improved F/G ($P<0.01$), however, compared with pigs fed the control. Overall (d 0 to 28), pigs fed WPC from Source 1 had greater ADG ($P<0.05$) than did pigs fed WPC from Source 3, but there were no treatment differences in ADFI and F/G. In summary, variation in growth performance with pigs fed WPC confirms our previous results in that variation between sources does exist. Furthermore, pigs fed diets containing high-quality WPC, from a reliable and consistent source, can improve ADG and have similar performance to pigs fed spray-dried animal plasma.

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

Introduction

Research previously reported at the 1998 Kansas State University Swine Day showed that high-protein whey protein concentrate (WPC) can improve growth performance of nursery pigs. However, in the Kansas State University Swine Day 2004 report, no improvements were shown when evaluating WPC. Variation between manufacturers in the production and processing of WPC potentially can alter its quality as an ingredient for nursery pig diets. Therefore, the objectives of this study were to compare the effects of five different sources of high-protein WPC on growth performance of nursery pigs and to further determine if WPC can replace spray-dried animal plasma in nursery diets.

Procedures

A total of 228 weanling pigs (initially 14.7 lb and 21 ± 3 d of age, PIC L210 × L42) were blocked by initial weight and randomly allotted to one of seven dietary treatments in an

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

unbalanced complete-block design. There were either five or six pigs per pen (equalized within block), with five replications for each control treatment and six replications for each WPC treatment.

All diets were fed in meal form (Table 2). All pigs were fed Phase 1 treatment diets from weaning to d 14 after weaning. There were seven experimental diets: negative control, with no WPC (control); positive control, with 5% spray-dried animal plasma (SDAP; American Proteins, Ames, IA); or the negative control diet and 5.0% WPC from Land O' Lakes (Source 1, St. Paul, MN); 5.0% WPC from Proliant (Source 2, Ames, IA); 5.0% WPC from CalPro Ingredients (Source 3, Corona, CA); 5.0% WPC from Formost Farms, USA (Source 4, Baraboo, WI); or 5.0% WPC from Agri•Mark (Source 5, Onalaska, WI). Synthetic amino acids were used in various amounts to maintain similar levels of soybean meal and amino acids for all diets except the control. All pigs were then fed the same common diet from d 14 to 28 after weaning. 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 contained one self-feeder and one nipple waterer to provide *ad libitum* access to feed and water. Average daily gain, ADFI, and F/G were determined by weighing pigs and feeders on d 7, 14, and 28 after weaning. Data were analyzed as an incomplete block design (5 replications of the two control treatments and 6 replications of the five WPC treatments), 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 WPC from Source 1 had greater ADG ($P<0.05$) than did pigs fed the control diet or diets containing WPC from Source 3. Pigs fed diets containing SDAP also had greater ADG and ADFI ($P<0.05$) than did pigs fed diets containing WPC from Source 3. Pigs fed all diets containing WPC tended to have poorer ADFI ($P<0.09$) than that of pigs fed diets containing SDAP. But all pigs fed diets containing WPC showed improved F/G ($P<0.01$), compared with that of pigs fed the control diet.

From d 14 to 28, pigs fed the control diet and pigs previously fed diets containing WPC from Source 2 had greater ADG than that of pigs fed diets containing WPC from Source 3. Pigs previously fed diets containing WPC from Source 2 had improved F/G, compared with that of pigs previously fed diets containing WPC from Source 3. There were no differences in ADFI.

Overall (d 0 to 28), pigs fed diets containing WPC from Source 1 had greater ADG ($P<0.05$) than did pigs fed diets containing WPC from Source 3; ADG of pigs fed diets containing WPC from all other sources were intermediate. There were no differences in ADFI and F/G.

The analyzed values (Table 1) for WPC and SDAP were very similar to those used in diet formulation. Analyzed amino acid and CP values for WPC from Sources 1, 2, 3, and 5 were slightly greater than those used in diet formulation, whereas analyzed values for WPC from Source 4 were slightly less, but the variation in WPC between analyzed and for-

mulated values would not be large enough to influence growth performance responses.

The variation in growth performance with pigs fed WPC does, however, confirm our previous results, in that variation between sources does exist. Differences in subsequent growth performance may be caused by manufacturer differences in milk product source, spray-drying and processing methods, and/or particle size. The use of WPC in this experiment showed that it can be a replacement for SDAP when a high-quality WPC is used.

Pigs fed diets containing high-quality whey protein concentrate, from a reliable and consistent source, can improve ADG and have similar performance to pigs fed spray-dried animal plasma.

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

Item	Whey Protein Concentrate Source					Spray-dried Animal Plasma
	1	2	3	4	5	
DM, %	93.09	92.58	94.67	92.62	94.69	90.85
CP, %	75.87	77.86	78.70	57.59	80.18	77.95
Ash, %	2.37	2.61	2.77	3.63	2.46	8.60
Amino acids, %						
Arginine	1.93	1.91	1.96	1.73	2.03	4.57
Histidine	1.57	1.60	1.60	1.29	1.56	2.61
Isoleucine	5.09	5.13	4.89	3.36	5.15	2.90
Leucine	8.28	8.51	8.47	6.18	8.69	7.51
Lysine	7.22	7.31	7.31	5.02	7.49	6.90
Methionine	1.65	1.62	1.67	1.15	1.64	0.69
Phenylalanine	2.63	2.71	2.75	2.17	2.65	4.38
Threonine	5.25	5.24	5.35	3.67	5.01	4.33
Tryptophan	1.71	1.79	1.76	1.22	1.61	1.38
Valine	4.76	4.76	4.66	3.34	4.82	5.20

[a]Values represent the means of one sample for each ingredient analyzed in duplicate. Values used in diet formulation are provided in parentheses.

Table 2. Diet Composition (As-fed Basis)

	Phase 1[a]							
		Spray-dried	Whey Protein Concentrate Source					
Ingredient, %	Control	Animal Plasma	1	2	3	4	5	Phase 2[b]
Corn	41.45	49.32	49.21	49.25	49.21	49.05	49.20	50.53
Soybean meal (46.5% CP)	40.33	27.52	27.51	27.49	27.51	27.50	27.51	32.39
Spray dried whey	15.00	15.00	15.00	15.00	15.00	15.00	15.00	---
Spray dried animal plasma	---	5.00	---	---	---	---	---	---
Whey protein concentrate	---	---	5.00	5.00	5.00	5.00	5.00	---
Whey permeate	---	---	---	---	---	---	---	8.50
Select menhaden fish meal	---	---	---	---	---	---	---	2.50
Soy oil	---	---	---	---	---	---	---	2.00
Monocalcium P (21% P)	1.50	1.20	1.50	1.50	1.50	1.50	1.50	1.20
Limestone	0.83	1.05	0.85	0.85	0.85	0.85	0.85	0.70
Salt	0.30	0.30	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	0.25	0.25
Trace mineral premix	0.15	0.15	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	0.08	0.06	0.05	0.06	0.16	0.06	0.20
DL-methionine	0.12	0.11	0.16	0.16	0.16	0.18	0.16	0.15
Total	100.00	100.00	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	1.50	1.50	1.45
ME, kcal/lb	1,483	1,490	1,482	1,482	1,482	1,483	1,482	1,458
CP, %	24.1	22.7	22.7	22.8	22.6	21.9	22.8	21.3
Ca, %	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.82
P, %	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.75
Available P, %	0.50	0.50	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.

Table 3. Growth Performance of Nursery Pigs Fed Whey Protein Concentrate from Different Sources[d]

Item	Control	Spray-dried Animal Plasma	Whey Protein Concentrate Source					Probability, P<			
			1	2	3	4	5	Trt	Control vs. WPC	SDAP vs. WPC	SE
d 0 to 14											
ADG, lb	0.45[bc]	0.53[ab]	0.55[a]	0.50[abc]	0.45[c]	0.52[abc]	0.52[abc]	0.24	0.15	0.49	0.047
ADFI, lb	0.64[ab]	0.67[a]	0.65[ab]	0.62[ab]	0.57[b]	0.63[ab]	0.62[ab]	0.32	0.36	0.09	0.045
F/G	1.42[a]	1.30[ab]	1.19[b]	1.25[b]	1.25[b]	1.21[b]	1.21[b]	0.08	0.01	0.24	0.078
d 14 to 28											
ADG, lb	1.45[a]	1.38[ab]	1.44[ab]	1.46[a]	1.36[b]	1.38[ab]	1.40[ab]	0.22	0.16	0.85	0.052
ADFI, lb	1.97	1.82	1.94	1.92	1.92	1.92	1.88	0.82	0.23	0.42	0.098
F/G	1.36[ab]	1.32[ab]	1.34[ab]	1.31[b]	1.41[a]	1.40[ab]	1.35[ab]	0.42	0.99	0.36	0.057
d 0 to 28											
ADG, lb	0.94[ab]	0.96[ab]	1.00[a]	0.98[ab]	0.91[b]	0.95[ab]	0.96[ab]	0.38	0.92	0.60	0.041
ADFI, lb	1.30	1.25	1.29	1.27	1.25	1.28	1.26	0.94	0.30	0.86	0.065
F/G	1.37	1.31	1.30	1.29	1.37	1.34	1.31	0.40	0.19	0.69	0.049

[abc]Means in the same row with different superscripts differ (P<0.05).

[d]A total of 200 weanling pigs, (PIC L210 × L42; 114 barrows and 86 gilts) initially 14.7 lb.

DETERMINING THE OPTIMAL LYSINE:CALORIE RATIO FOR GROWTH PERFORMANCE OF PIC NURSERY PIGS

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

Summary

Two studies were conducted to evaluate the effects of increasing dietary lysine and energy density on nursery pig performance. Experiment 1 was organized as a combination of two simultaneous experiments,with one set of diets consisting of five treatments with increasing true ileal digestible (TID) lysine (1.11, 1.19, 1.26, 1.34, and 1.42%) and the second set of diets consisting of five treatments with increasing energy density (1,341, 1,408, 1,475, 1,542, and 1,609 kcal/lb). The highest level of both lysine and energy density (1.42% and 1,609 kcal/lb, respectively) were combined as one diet and used in both the lysine and energy-density titrations, to give a total of 9 diets for the 10 treatments. Pigs (PIC, avg BW = 22.5 lbs) were randomly allotted to eight replications with five pigs per pen, on the basis of BW. Overall (d 0 to 21) in Experiment 1, increasing TID lysine linearly increased (P<0.01) ADG and improved (linear, P<0.01) feed efficiency. Increasing energy density had no effect on ADG, but it decreased (linear, P<0.01) ADFI, which resulted in a linear (P<0.01) improvement in F/G. Regression analysis of the response surface was used to predict the optimal lysine:calorie ratios for ADG and F/G of 4.06 and 3.92 g lysine/Mcal ME for the PIC pigs used in this experiment. In Experiment 2, pigs (PIC, avg BW = 16.6 lbs) were fed diets with two different energy densities (1.34 or 1.49 Mcal ME/lb) with TID lysine:calorie ratios ranging from approximately 3.5 to 4.5 g/Mcal ME. There was an energy density × TID lysine:calorie ratio interaction observed for F/G. Pigs fed the low-energy diets had the greatest ADG, at a lysine:calorie ratio of 4.55. For pigs fed the high-energy diets, ADG improved as the lysine:calorie ratio improved to 4.26 g of TID lysine/Mcal ME. There was a quadratic (P<0.03) improvement in feed efficiency as the lysine:calorie ratios were increased for the pigs fed the low-energy diet, with the best F/G value observed at 4.55, but the pigs fed the high-energy diets experienced a linear (P<0.01) improvement in F/G as the lysine:calorie ratios were increased. These results suggest that the optimal lysine-to-calorie ratio is 4.26 to 4.55 g of TID lysine/Mcal ME for 20- to 50-lb PIC pigs in these facilities.

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

Introduction

To satisfy the demands of consumers, modern pork producers have increased the supply of lean pork though genetic selection for maximal lean gain potential. The requirements for lysine and energy for gain have increased in today's pig, due to an increase in efficiency in depositing lean tissue. But

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

dietary energy intake provided by cereal grains may be limited by the gut capacity of the growing pig. Therefore, for optimal protein utilization, the amino acid requirement of the nursery pig must be expressed in relation to the energy density of the diet.

Nutritionists and producers typically add fat to swine diets in an attempt to raise the energy value of the diet and improve growth rate and efficiency. But most studies have determined a lysine:calorie ratio based on titrating lysine on a single energy value used in the experimental treatments. Therefore, the optimum dietary lysine-to-calorie ratio may be affected by the level of energy intake. By determining the requirements for lysine and energy concurrently, a more precise ratio should be determined.

Our objectives in this study were to determine an optimal lysine:calorie ratio for maximal growth and feed efficiency of the nursery pig by titrating a lysine and energy requirement simultaneously, and then to validate the lysine:calorie ratio by titrating lysine at two energy levels.

Procedures

Experiment 1. Three hundred sixty PIC 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 (1.11, 1.19, 1.26, 1.34, and 1.42%) and the second set of diets consisting of five treatments with increasing energy density (1,341, 1,408, 1,475, 1,542, and 1,609 kcal of ME per lb). The highest levels of both lysine and energy density (1.42% and 1,609 kcal, respectively) diet were combined as one treatment and used in both lysine and energy-density titrations, to give a total of 9 diets for the 10 treatments. The diets containing 1.11% and 1.42% TID lysine were blended to form the intermediate diets for the lysine titration (Table 1). The diets containing 1,341 kcal and 1,609 kcal were blended to form the intermediate 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 waterer to provide *ad libitum* access to feed and water. 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 PIC pigs (BW of 16.6 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:calorie ratios, with differing energy density of the diets. Energy levels (1,340 and 1,490 kcal of ME/lb) were selected because they were in the linear portion of the response in F/G in Experiment 1. Diets for both energy levels were formulated by blending different percentages of the highest and lowest lysine:calorie ratio diets. In the low-energy diets, and partly replaced corn to avoid confounding the response with changes in energy sources. Dietary mineral and vitamin amounts were formulated to meet or exceed National Research Council recommendations.

Analysis of variance was used to analyze the data as a randomized complete-block design by using MIXED procedures of SAS. The Least Squares Difference (LSD) test was used to determine differences within energy density of the treatments (P<0.10).

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 1.11 to 1.42%. Increasing TID lysine also improved (linear, P<0.01) F/G, although there was no improvement in feed efficiency after 1.34% TID lysine. Increasing the energy level from 1,342 to 1,609 kcal ME in the diet had no effect on ADG, but there was a trend for a linear decrease in gain as energy increased. On the other hand, ADFI decreased (linear, P<0.01), improving (linear, 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, 2, 3, and 4). 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:calorie range (Table 5). Regression analysis of the response surface resulted in estimated optimal lysine-to-calorie ratios for ADG and F/G of 4.06 and 3.92 g TID lysine per Mcal ME, respectively.

Experiment 2. From day 0 to 21, (Table 6) increasing the lysine:calorie ratio increased (P<0.01) ADG and lysine intake, whereas increasing the energy density decreased (P<0.01) ADFI. Pigs fed the diets containing 1,340 kcal/lb of ME had a linear (P<0.01) response to ADG as the lysine:calorie ratio increased. Pigs fed the diets containing 1,490 kcal/lb of ME showed no effect on ADG as the lysine:calorie ratio increased. There was no effect on ADFI for pigs fed diets with either the 1,340 or 1,490 kcal/lb of ME, but there was a linear (P<0.11; P<0.19, respectively) trend to decreased intake. There was an energy density × lysine:calorie ratio interaction (P<0.10) observed for F/G. Pigs fed the 1,340 kcal/lb of ME had improved (quadratic, P<0.03) F/G as the lysine:calorie ratio increased, whereas pigs fed the diets containing 1,490 kcal/lb of ME tended to have improved (linear, P<0.01) F/G as the lysine:calorie ratio increased. Pigs fed both energy-density diets tended to increase (linear, P<0.01) lysine intake as the lysine:calorie ratio increased.

There are many factors that may change the lysine and energy requirement of the young, rapidly growing pig, such as feed intake and genetic potential for gain. Also, determining the optimal lysine-to-calorie ratio for different energy densities is a critical response to study based on production and feed parameters. In our lab, 20- to 50-lb Gentiporc pigs previously were used for a similar experiment and were found to require approximately 10 to 11 g/d of TID lysine intake to maximize growth performance, with a suggested optimal lysine to calorie ratio is 3.30 to 3.87 g of TID lysine/Mcal ME. In the present study, it was determined that increasing the energy density of the diet improved feed efficiency, but there was no response in ADG or ADFI for PIC pigs. In addition, it seems that these pigs require approximately 9 to 10 g/d of TID lysine intake to optimize growth performance. These results suggest that the optimal lysine-to-calorie ratio is 4.26 to 4.55 g of TID lysine/Mcal ME for 20- to 50-lb PIC pigs in this environment. These finding will need to be further investigated because the pigs in the second experiment weighed approximately 17 pounds at the beginning of the trial.

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

	True Ileal Digestible Lysine (%)/ME (kcal)		
Item, %	1.11/1,605	1.42/1,609	1.41/1,341
Corn	54.90	54.11	49.11
Soybean meal (46.5% CP)	36.66	36.65	6.65
Soybean oil	5.00	5.00	0.00
Sand	0.00	0.00	10.00
Monocalcium P (21% P, 18.5% Ca)	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	0.24	0.24
Total	100.00	100.00	100.00

[a]Diets that were formulated to be 1.11/1,605 lys/ME and 1.42/1,609 lys/ME were blended to achieve TID lysine concentrations of 1.11, 1.19, 1.26, 1.34, and 1.42%.
[b]Diets that were formulated to be 1.41/1,341 lys/ME and 1.42/1,609 lys/ME were blended to achieve ME concentrations of 1,341, 1,408, 1,475, 1,542, and 1,609 kcal/lb.

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

	1,340 kcal/lb[a]		1,490 kcal/lb[b]	
Item, % Lysine:calorie Ratio, g/Mcal:	3.50	4.55	3.55	4.49
Corn	52.41	56.57	63.39	62.61
Soybean meal (46.5% CP)	34.06	29.10	33.10	33.10
Sand	10.00	10.00	0.00	0.00
Monocalcium P (21% P, 18% Ca)	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	0.03	0.00	0.03
L-threonine	0.00	0.20	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	0.03	0.22	0.03	0.22
Total	100.00	100.00	100.00	100.00

[a]Diets were formulated to contain 1.34 Mcal/lb of ME, with 3.50, 3.77, 4.03, 4.29, and 4.55 lysine:calorie ratios.
[b]Diets were formulated to contain 1.49 Mcal/lb of ME, with 3.55, 3.79, 4.03, 4.26, and 4.49 lysine:calorie ratios.

Table 3. The Effect of Increasing TID Lysine for the Growing Pig, Experiment 1[a]

	TID lysine, %						Probability, P <	
Item	1.11	1.19	1.26	1.34	1.42	SE	Linear	Quadratic
d 0 to 21								
ADG, lb	1.22	1.26	1.26	1.30	1.32	0.08	0.01	0.98
ADFI, lb	1.77	1.77	1.78	1.73	1.75	0.05	0.58	0.93
F/G	1.48	1.40	1.42	1.33	1.33	0.03	0.01	0.54

[a]Each value is the mean of eight replications with 5 pigs (initially 20.5 lb) per pen.
[b]Average metabolizable energy was 1,607 kcal/lb and is similar for all diets.

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

	Metabolizable Energy, kcal/lb						Probability, P <	
Item	1,341	1,408	1,475	1,542	1,609	SE	Linear	Quadratic
d 0 to 21								
ADG, lb	1.37	1.37	1.35	1.33	1.32	0.08	0.11	0.83
ADFI, lb	2.05	1.95	1.92	1.81	1.75	0.05	0.01	0.99
F/G	1.52	1.42	1.42	1.35	1.33	0.03	0.01	0.39

[a]Each value is the mean of eight replications, with 5 pigs (initially 20.5 lb) per pen.
[b]Average TID lysine content for increasing energy density is 1.42%, 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			
1.33	1.38	1,522	3.92
1.35	1.34	1,562	3.88
1.40	1.23	1,477	3.76
1.45	1.12	1,402	3.61
ADG			
1.32	1.43	1,597	4.06

[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:calorie Ratio on Pig Performance (d 0 to 21), Experiment 2

ME, Mcal	Lysine/ME Ratio	ADG, lb	ADFI, lb	F/G	Total Lysine Intake, g/d
1.34	3.50	0.99	1.60	1.63	7.50
	3.77	1.00	1.59	1.60	7.98
	4.03	1.04	1.66	1.61	8.93
	4.29	1.11	1.71	1.55	9.80
	4.55	1.12	1.64	1.45	10.01
1.49	3.55	1.03	1.51	1.50	8.02
	3.79	1.06	1.50	1.44	8.49
	4.03	1.05	1.48	1.42	8.88
	4.26	1.11	1.49	1.34	9.48
	4.49	1.06	1.44	1.37	9.66
SE		0.05	0.08	0.03	0.44
		Probability, P <			
Main effects					
Energy		0.61	0.01	0.01	0.68
Lysine/ME		0.01	0.55	0.01	0.01
Energy × lysine/ME		0.28	0.26	0.10	0.15
1.34 ME Mcal, Lysine/ME ratio					
Linear		0.01	0.11	0.01	0.01
Quadratic		0.71	0.41	0.03	0.46
1.49 ME Mcal, Lysine/ME ratio					
Linear		0.26	0.19	0.01	0.01
Quadratic		0.31	0.74	0.19	0.66

[a]Each value is the mean of seven replications, with 5 pigs (initially 16.6 lb) per pen.

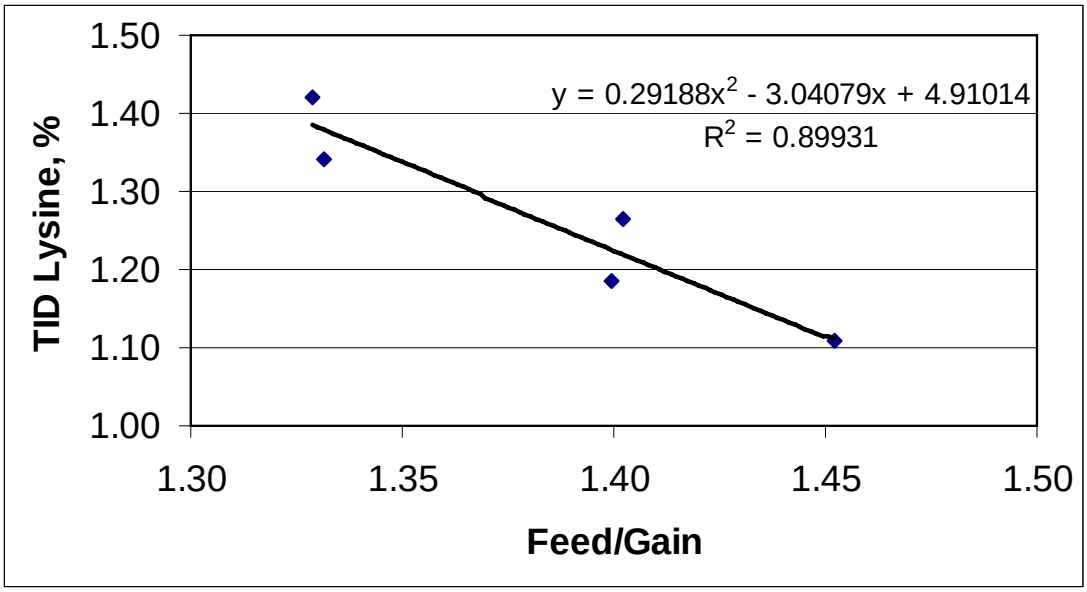


Figure 1. Regression Analysis for Feed Efficiency of Lysine.

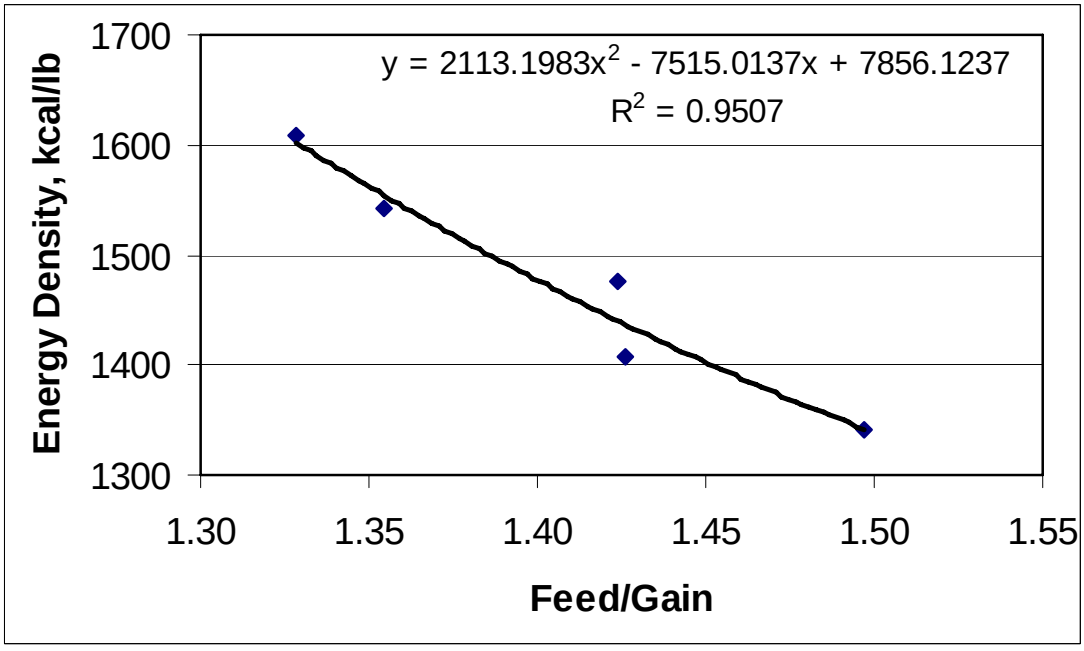


Figure 2. Regression Analysis for Feed Efficiency of Energy Density.

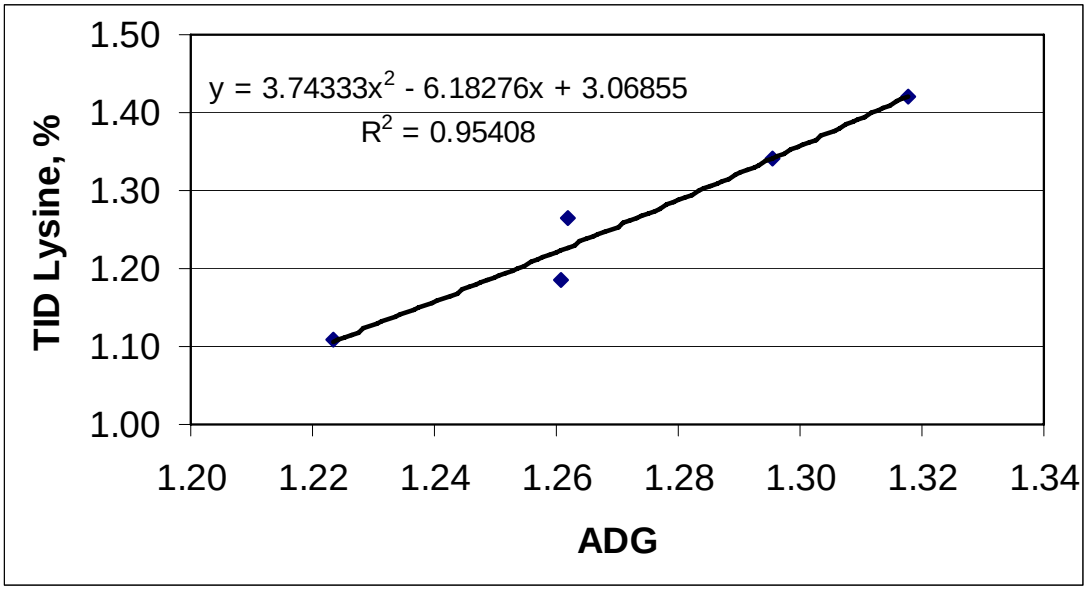


Figure 3. Regression Analysis for ADG of Lysine.

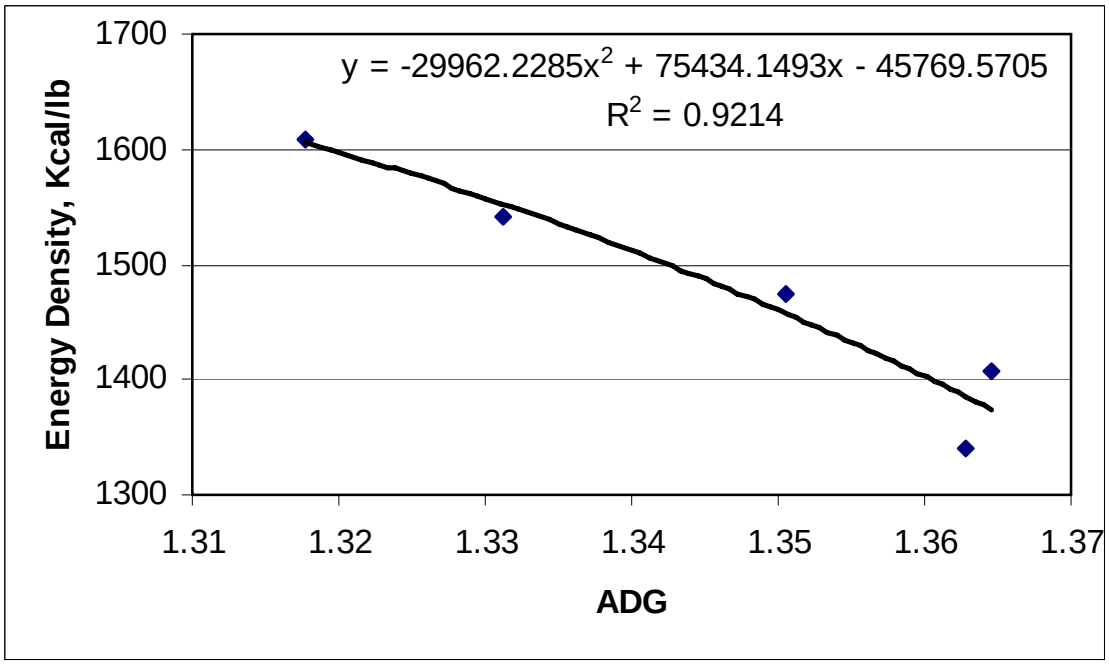


Figure 4. Regression Analysis for ADG of Energy Density.

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 involving 360 pigs (PIC, avg. BW = 22.0 lb) was conducted 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:lysine ratio. This trial was organized as a combination of two simultaneous experiments, with one set of diets consisting of five increasing TID lysine concentrations (1.05, 1.15, 1.25, 1.35, and 1.45%) and the second set of diets consisting of five increasing TID TSAA concentrations (0.61, 0.69, 0.76, 0.83, and 0.90%). The highest concentrations of both lysine and TSAA (1.45% and 0.90%, 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 initial BW. Average daily gain and F/G improved (quadratic, P<0.01) with increasing TID lysine. The largest improvement in growth rate and feed efficiency for PIC pigs in these facilities occurred as the TID lysine increased to 1.25 and 1.35%, respectively; there was little improvement in performance thereafter. Increasing TID TSAA increased (quadratic, P<0.01) ADG and improved (quadratic, P<0.01) F/G, although the largest increases in ADG and F/G occurred as TID TSAA increased from 0.61 to 0.76%, with smaller improvements from 0.76 to 0.90%. Average daily gain and F/G values were plotted as the dependent variables in a regression analysis, with the TID lysine and TSAA concentrations on the Y axis. Regression analysis of the response surface resulted in an estimated TID TSAA-to-lysine ratio range of approximately 55 to 56% for optimal ADG and F/G.

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

Introduction

The total sulfur amino acid (TSAA) requirement for the 20- to 50-lb pig has been shown to be adequate for growth in conventional diets that are based on corn soybean meal. In recent years, however, the increasing price of soybean meal (SBM) and the decreasing price of crystalline lysine have increased the usage of crystalline lysine and other amino acids, such as methionine. Thus, it is essential

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

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

that nutritionists can accurately define the ratio of other amino acids to lysine to properly utilize synthetic amino acids and reduce feed costs.

The National Research Council (NRC) reports TID lysine and TID TSAA requirements of 1.01 and 0.58%, respectively, for the 20- to 50-lb pig. Therefore, this would equate to a TSAA:lysine ratio of 57%. Previous experiments in our lab have estimated the TSAA:lysine ratio for the 20- to 50-lb pig to range from 55 to 61% for ADG and 57 to 61% for F/G, although many other studies have reported a larger range.

The variability in TSAA:lysine requirements ratio reported in other trials may be explained by the use of differing response criteria, weight and genetics of pigs, and the bioavailability and type of diet used in these studies. Also, it may be common to extrapolate lysine requirements from previous studies or the NRC estimates to form a ratio with specific amino acids that are being studied. The aforementioned procedures are commonly performed in experiments to save time, but they are not as precise as determining a requirement simultaneously for lysine and TSAA.

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

Procedures

Three hundred sixty PIC pigs were blocked by weight (initially 22.0 lb) and 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 increasing TID lysine concentrations (1.05, 1.15, 1.25, 1.35, and 1.45%); other crystalline amino acids were added to meet minimum ratios and to ensure that lysine was first limiting. The second set of five diets was formulated to 1.45% TID lysine, with increasing TID TSAA (0.61, 0.69, 0.76, 0.83, and 0.90%). The highest concentrations of both lysine and TSAA (1.45% and 0.90%, respectively) were combined as one diet and used in both lysine and TSAA titrations, to give a total of 10 treatments. The diets containing 1.05% TID lysine with 0.65% TID TSAA, 1.45% TID lysine with 0.61% TID TSAA, and 1.45% TID lysine with 0.90% TID TSAA were blended to form all intermediate 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 Kansas State University Segregated Early 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 samples 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 based on 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 (quadratic, $P<0.01$) ADG and improved (quadratic $P<0.01$) F/G; the largest increase in ADG and F/G occurred as TID lysine increased from 1.05 to 1.25 and 1.35%, respectively, with little or no improvement thereafter. Increasing TID TSAA increased (quadratic, $P<0.01$) ADG and improved (quadratic, $P<0.01$) F/G. There was a large improvement in ADG and F/G when TID TSAA was increased from 0.61 to 0.76 and 0.83%, respectively, but the response receded thereafter.

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 protein deposition was limited when dietary TSAA was insufficient, resulting in increased amounts of urea in plasma. As dietary methionine increased and approached the pig's requirement, however, 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.

A trend line was fit through the data to develop a regression equation to predict the TID lysine and TSAA requirement, which were used to estimate the TID TSAA:lysine ratio. The values for ADG and F/G from the individual lysine and TSAA trials must overlap to allow this approach to work. Average daily gain and F/G were plotted on the Y axis and TID lysine or TSAA was plotted on the X axis to develop a trend line equation (Figure 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:TSAA ratio. Regression analysis of the response surface resulted in an estimated optimal TID TSAA:lysine ratio of approximately 55 to 56% for ADG and F/G. The resulting TSAA:lysine ratio is very similar to the ratio of values reported by the National Research Council of 57%.

The future economic advantage of determining the suitable TSAA:lysine ratio is obvious with the likely increase of additional crystalline lysine in the diet, combined with the questionable stability of protein sources. By establishing the ratio for optimal growth performance, swine diets can be balanced accordingly. This research suggests that the optimal TSAA:lysine ratio for the pig up to 50 lb is from 55 to 56%.

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

	True Ileal Digestible Lysine/TSAA, %		
Item, %	1.05/0.65	1.45/0.90	1.45/0.61
Corn	60.02	60.00	60.00
Soybean meal (46.5% CP)	33.42	33.43	33.44
Soybean oil	1.50	1.50	1.50
Monocalcium P (21% P, 18% Ca)	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	0.02
L-valine	0.03	0.08	0.08
L-tryptophan	---	0.03	0.03
L-threonine	0.02	0.27	0.27
Alimet®	0.05	0.33	---
L-lysine HCl	0.02	0.53	0.53
Corn starch	1.17	0.06	0.38
Total	100.00	100.00	100.00

[a]Diets that were formulated to contain 1.05/0.65 TID lysine/TSAA and 1.45/0.90 TID lysine/TSAA were blended to achieve TID lysine concentrations of 1.05, 1.15, 1.25, 1.35, and 1.45%.

[b]Diets that were formulated to contain 1.45/0.61 TID lysine/TSAA and 1.45/0.90 TID lysine/TSAA were blended to achieve TID TSAA concentrations of 0.61, 0.69, 0.76, 083, and 0.90%.

Table 2. Effects of Increasing True Ileal Digestible (TID) Lysine in 20- to 50-lb Nursery Pigs[a]

	TID Lysine, %						Probability, P <	
Item	1.05	1.15	1.25	1.35	1.45	SE	Linear	Quadratic
d 0 to 21								
ADG, lb	1.07	1.18	1.20	1.19	1.21	0.04	0.01	0.01
ADFI, lb	1.68	1.75	1.71	1.67	1.69	0.06	0.45	0.28
F/G	1.57	1.47	1.42	1.40	1.39	0.02	0.01	0.01
Plasma urea N, mg/dL	4.92	4.20	3.66	3.33	3.29	0.31	0.01	0.15

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

Table 3. Effects of Increasing True Ileal Digestible (TID) Total Sulfur Amino Acids (TSAA) in 20- to 50-lb Nursery Pigs[a]

	TID TSAA, %						Probability, P <	
Item	0.61	0.69	0.76	0.83	0.90	SE	Linear	Quadratic
d 0 to 21								
ADG, lb	1.12	1.18	1.24	1.23	1.21	0.04	0.01	0.01
ADFI, lb	1.68	1.68	1.73	1.69	1.69	0.06	0.58	0.43
F/G	1.49	1.40	1.38	1.37	1.39	0.02	0.01	0.01
Plasma urea N, mg/dL	4.07	4.15	3.15	2.95	3.29	0.31	0.01	0.22

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

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

Response	TID Lysine	TID TSAA	TID TSAA:Lysine Ratio
F/G			
1.50	1.10	0.60	54.9
1.48	1.13	0.62	55.1
1.44	1.24	0.69	55.5
1.40	1.39	0.78	56.0
ADG			
1.21	1.44	0.80	55.8
1.18	1.18	0.76	64.5
1.15	1.01	0.69	67.9
1.12	0.94	0.58	62.1

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

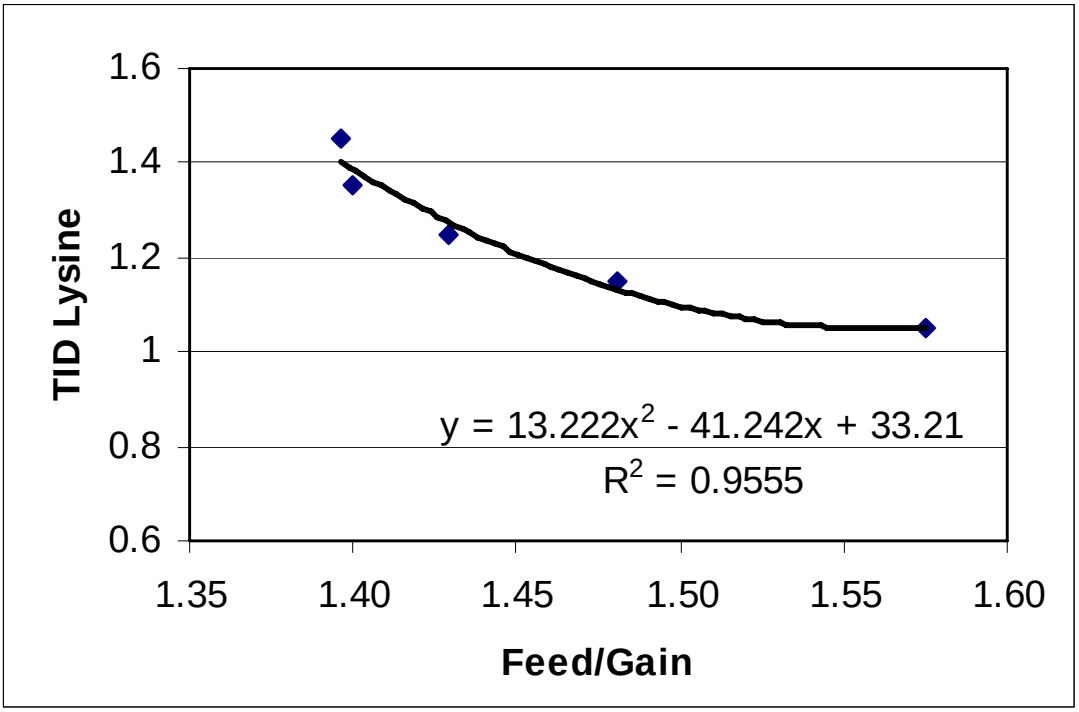


Figure 1. Regression Analysis for Feed Efficiency of Lysine.

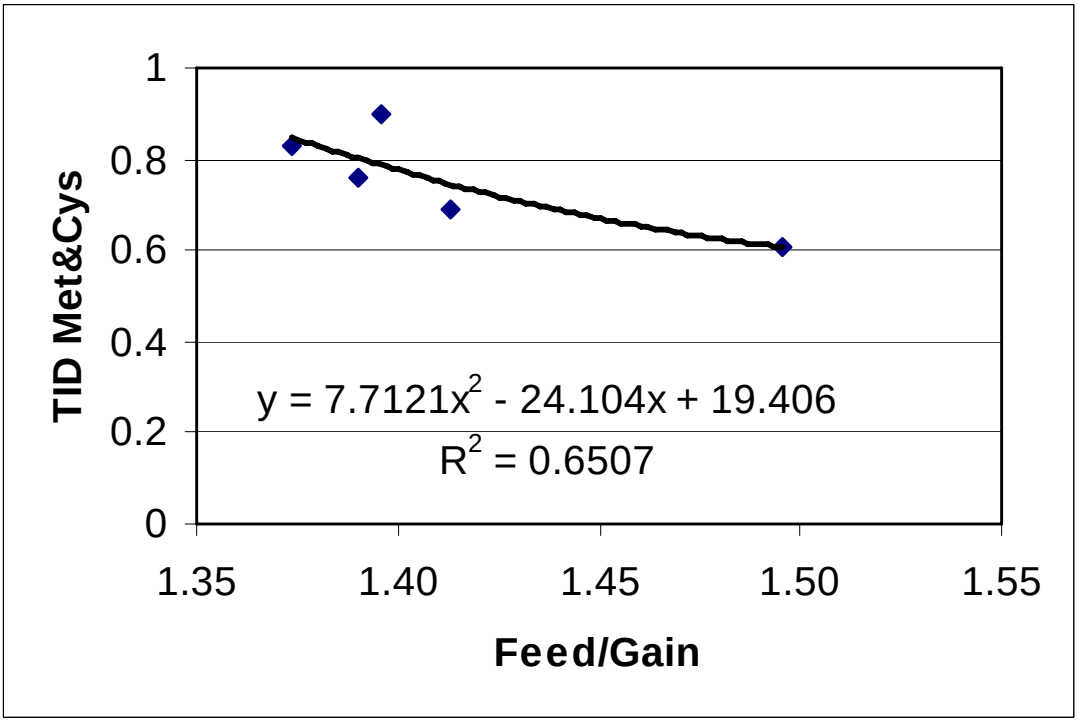


Figure 2. Regression Analysis for Feed Efficiency of TSAA.

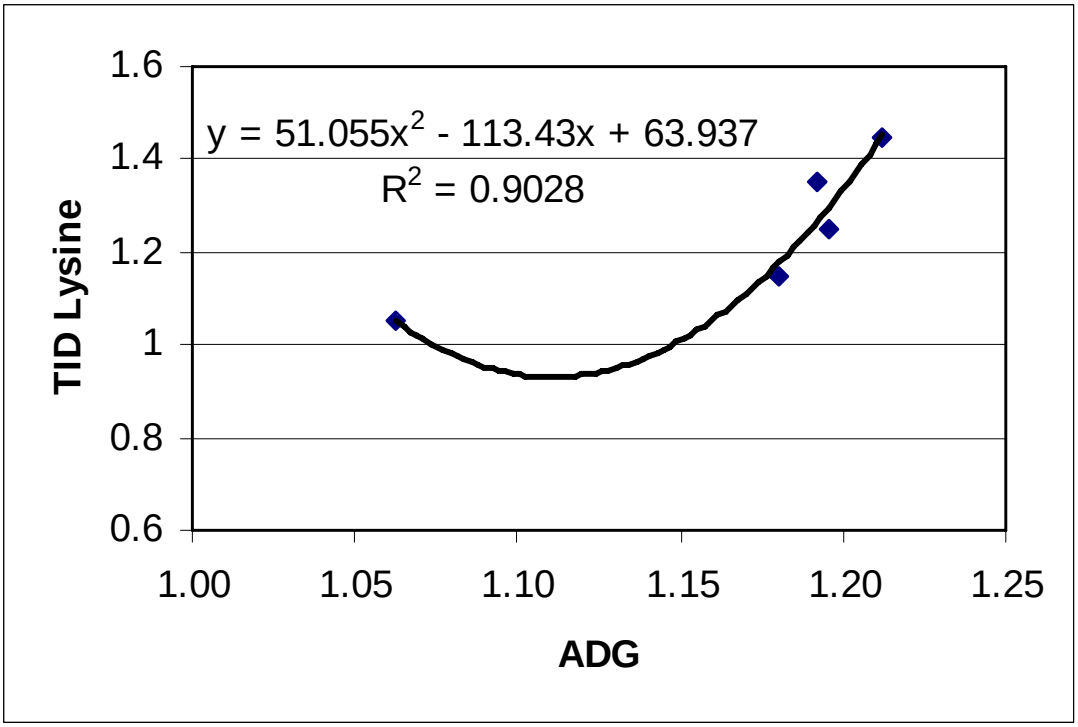


Figure 3. Regression Analysis for ADG of Lysine.

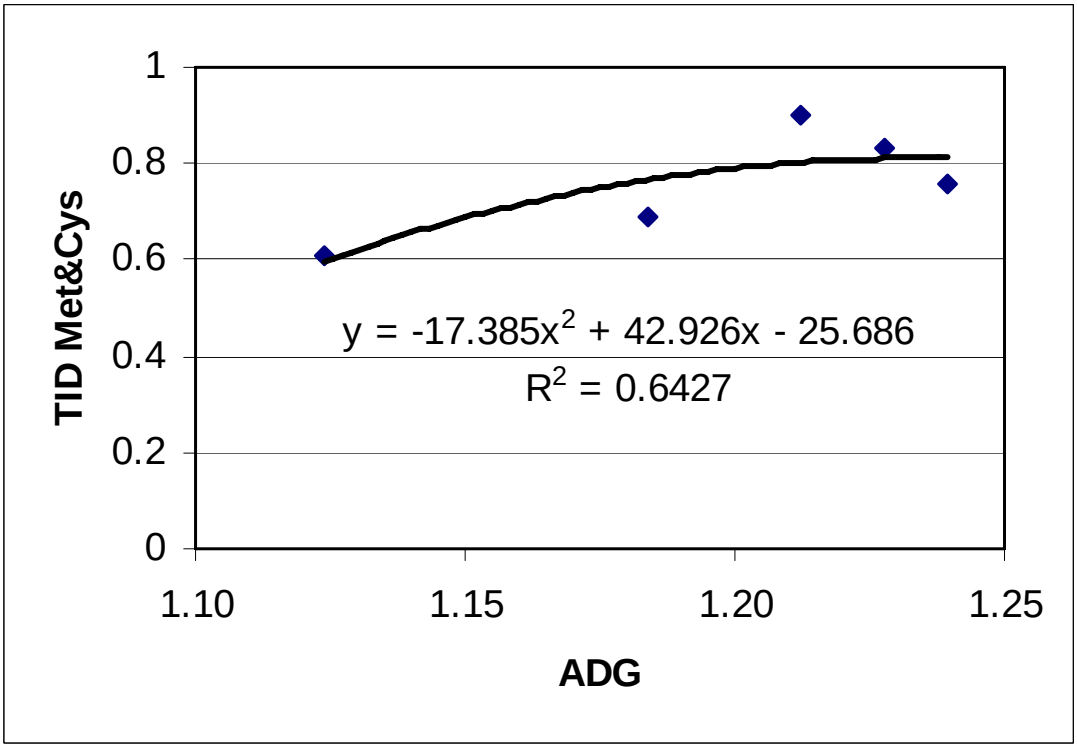


Figure 4. Regression Analysis for ADG of TSAA.

NURSERY PIG PERFORMANCE IN RESPONSE TO MEAL AND PELLETED DIETS FED WITH IRRADIATED OR NON-IRRADIATED SPRAY-DRIED ANIMAL PLASMA

C. N. Groesbeck, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, S. S Dritz[1], J. L. Nelssen, J. Bergstrom[2], C. R. Neill, K. R. Brown, and N. Z. Frantz

Summary

A 25-d trial was conducted to determine the effects of feeding meal and pelleted diets, with or without irradiated spray-dried animal plasma (SDAP; AP 920), on the growth performance in nursery pigs. A total of 192 pigs (initially 13.2 ± 1.9 lb and 21 ± 3 d of age) were used, with 6 pigs per pen and 6 pens per treatment. Pigs were randomly allotted in a 2 × 2 factorial to pens, blocked by weight, and randomly allotted to one of four dietary treatments. The main effects were diet form, meal or pellet, and either irradiated SDAP or non-irradiated SDAP. The experimental treatments consisted of a single diet that was fed in either meal or pelleted form, with or without irradiation of SDAP for Phase 1 (d 0 to 11), and a common diet for Phase 2 (d 11 to 25). Pig fed pelleted diets from d 0 to 3 had a greater ADG, ADFI, and improved F/G ($P<0.03$) than did pigs fed meal diets. Irradiation of SDAP had no effect on performance from d 0 to 3; for d 3 to 11, however, there was a diet form × SDAP irradiation interaction ($P < 0.01$), and for d 0 to 11 there was interaction for ADG and F/G ($P<0.07$). Pigs fed irradiated SDAP in meal form had similar growth performance to those fed pelleted treatments. For producers that manufacture their own Phase 1 diet in meal form, use of irradiated SDAP can result in performance equal to that of nursery pigs fed a pelleted diet.

(Key Words: Nursery Pig, Meal, Pellet, Spray-dried Animal Plasma, Irradiation.)

Introduction

The importance of starting pigs on feed is always emphasized to ensure that the pigs get off to a good start, and is critical for long-term performance. Specialty proteins such as spray-dried animal plasma (SDAP), fish meal, and dried whey are used to stimulate feed intake and start pigs on feed. These ingredients are very expensive and, with the added cost of pelleting, the alternative of feeding meal-based diets is being re-evaluated. Recent studies suggest that nursery pigs started on pelleted diets have increased gain and feed intake, compared with that of pigs started on meal diets. The heat and conditioning of ingredients before pelleting may be contributing to the improved performance seen when using pellets. It has also been demonstrated that irradiation of SDAP significantly reduces bacteria counts and results in an improved nursery pig performance. Therefore, the objective of our study was to determine the effects on nursery pig performance of feeding regular or irradiated SDAP in either meal or pelleted starter diets.

[1]Food Animal Health & Management Center, College of Veterinary Medicine
[2]Kerber Milling, Emmetsburg, IA.

Procedures

A total of 192 pigs (initially 13.2 ± 1.9 lb and 21 ± 3 d of age) were used in a 25-d growth assay, with 6 pigs per pen and 6 pens per treatment. Pigs were randomly allotted to pens and blocked by weight and allotted to one of four dietary treatments arranged in a 2 × 2 factorial. Main effects included diet form, meal or pellet, and either non-irradiated or irradiated SDAP. The experimental treatments consisted of one diet (Table 1) fed in either meal or pelleted form, with or without irradiation of SDAP (AP 920; American Protein, Ames, IA) for Phase 1, d 0 to 11. For Phase 2, (d 11 to 25), all pigs were fed a common diet in meal form. The SDAP was irradiated at the Iowa State University Linear Accelerator Facility, with an average irradiation dose of 11.92 kGy. All diets were manufactured at Kerber Milling, Emmetsburg, IA. Total bacterial plate counts and total coliform counts were analyzed on the plasma sources and each of the diets after manufacturing. Data was analyzed by using Proc MIXED procedures in SAS 8.1.

Results and Discussion

Irradiation of the SDAP reduced the total bacterial plate count (Table 2). Pelleting also reduced the total plate count, compared with that of the non-irradiated SDAP and the meal diets. The meal diet with the irradiated plasma source had only a slightly reduced total bacterial plate count, compared with that of the non-irradiated meal diet. Pigs fed pelleted diets from d 0 to 3 had greater ADG and ADFI, and an improved F/G ($P<0.03$), compared with those fed meal diets. Irradiation of SDAP had no effect on pig performance from d 0 to 3; for d 3 to 11, however, there was a diet form × SDAP irradiation interaction ($P<0.01$), and for d 0 to 11 there was an interaction for ADG and F/G ($P<0.07$). Pigs fed irradiated SDAP in meal form had similar performance to those fed the pelleted treatments. From d 11 to 25, all pigs were fed a common diet, in meal form; pigs previously fed the non-irradiated SDAP meal diet had reduced growth performance through d 25, compared with performance of those fed the irradiated SDAP meal diet and both of the pelleted treatments.

In conclusion, pigs feed pelleted diets had greater improvement in ADG, ADFI, and F/G ($P<0.03$) from d 0 to 3 than did pigs fed both meal treatments, but pigs fed the diet with irradiated SDAP had similar overall growth performance to that of pigs fed both of the pelleted treatments. For producers that manufacture their own Phase 1 diet in meal form, use of irradiated SDAP can result in performance equal to that of nursery pigs fed a pelleted diet.

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

Item	d 0 to 11[a]	d 11 to 25[b]
Corn	44.02	53.71
Soybean meal (46.5% CP)	19.40	31.54
Spray dried whey	20.00	10.00
Spray dried animal plasma	5.00	---
Menhaden fish meal	5.00	---
Soy oil	3.00	---
Monocalcium P (21% P)	0.75	1.50
Limestone	0.65	0.95
Salt	0.25	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Antibiotic[c]	0.70	0.70
Zinc oxide	0.38	---
L-threonine	0.08	0.13
L-lysine HCl	0.23	0.33
DL-methionine	0.15	0.15
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.50	1.30
ME, kcal/lb	1,552	1,474
Protein, %	22.6	20.9
Ca, %	0.88	0.84
P, %	0.80	0.76
Available P, %	0.57	0.46
Lysine:calorie ratio, g/Mcal	4.38	4.00

[a]The Phase 1 (d 0 to 11) diet was fed in either meal or pelleted form, with irradiated SDAP or non-irradiated SDAP.
[b]The Phase 2 (d 11 to 25) diet was a common diet fed to all pigs in meal form.
[c] Neo-Terramycin® 10/10.

Table 2. Aerobic Bacteria Concentration

Item	Total Plate Count, CFU/g	Total Coliform Count, CFU/g
Spray-dried animal plasma		
Non-irradiated	1.1×10^5	$< 1.0 \times 10^1$
Irradiated[a]	$< 1.0 \times 10^1$	$< 1.0 \times 10^1$
Diet with non-irradiated plasma		
Meal	2.6×10^4	3.9×10^2
Pellet	2.0×10^3	$< 1.0 \times 10^1$
Diet with irradiated plasma		
Meal	2.1×10^4	$< 1.0 \times 10^1$
Pellet	4.8×10^3	$< 1.0 \times 10^1$

[a]Spray-dried animal plasma was irradiated at 11.92 kGy.

Table 3. Effects of Meal and Pelleted Diets, with or without Irradiation of Spray-dried Animal Plasma[a]

	Non-irradiated Plasma		Irradiated Plasma			Probability, P <		
Data	Meal	Pellet	Meal	Pellet	SE	Diet Form	Plasma Irradiation	Diet Form × Plasma Irradiation
d 0 to 3								
ADG	0.50	0.65	0.48	0.68	0.05	0.002	0.95	0.71
ADFI	0.29	0.37	0.26	0.32	0.03	0.01	0.85	0.67
F/G	0.58	0.57	0.64	0.55	0.02	0.03	0.45	0.12
d 3 to 11								
ADG	0.67	0.85	0.87	0.88	0.04	0.003	0.001	0.01
ADFI	0.94	0.99	1.03	0.99	0.03	0.86	0.16	0.12
F/G	1.40	1.19	1.18	1.12	0.03	0.0001	0.0001	0.01
d 0 to 11								
ADG	0.62	0.79	0.77	0.83	0.03	0.001	0.003	0.05
ADFI	0.76	0.82	0.83	0.82	0.03	0.12	0.37	0.15
F/G	1.22	1.04	1.09	0.99	0.02	0.003	0.0001	0.07
d 11 to 25								
ADG	0.88	0.96	0.96	0.95	0.03	0.10	0.08	0.03
ADFI	1.13	1.28	1.25	1.27	0.04	0.01	0.08	0.04
F/G	1.30	1.33	1.31	1.34	0.01	0.09	0.85	0.80
d 0 to 25								
ADG	0.78	0.89	0.88	0.90	0.03	0.002	0.01	0.02
ADFI	0.99	1.09	1.09	1.09	0.04	0.05	0.08	0.06
F/G	1.27	1.23	1.23	1.21	0.02	0.07	0.06	0.57

[a]A total of 192 pigs (six pigs per pen and 8 pens per treatment) with an average initial weight of 13.9 ± 1.8 lb were used in the study.

THE EFFECTS OF MEAL TRANSITION DIETS ON NURSERY PIG GROWTH PERFORMANCE IN A COMMERCIAL ENVIRONMENT

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

Summary

A total of 2,016 pigs (initially 12.6 lb and 18 ± 2 d of age) were used in a 28-d growth assay to evaluate the current feed-budget allocations for SEW, Transition, and Phase 2 diets fed in meal form in a commercial environment. Pigs were allotted to one of six treatments, with a variety of feed budgets: 1) pelleted diets with 1 lb/pig of SEW diet (6.7% plasma) and 3 lb/pig of Transition diet (2.5% plasma); 2) pelleted diets with 0.5 lb/pig of SEW diet (6.7% plasma) and 1 lb/pig of Transition diet (2.5% plasma); 3) meal diet with 2 lb/pig Transition diet (2.5% plasma); 4) meal diet with 4 lb/pig of Transition diet (2.5% plasma); 5) meal diet with 2 lb Transition diet (4% plasma); and 6) meal diet with 4 lb Transition diet (4% plasma). After the allotted amount of feed was distributed to the pens as described in the budget, all treatments were fed 12 lb/pig of a Phase 2 meal diet, and then a Phase 3 meal diet for the duration of the trial. From day 0 to 10 and for the overall period, the pigs fed the pelleted SEW and Transition diets grew faster, and had better feed efficiency, lower removal rates (culls), and greater margin over feed cost than did the pigs fed the meal-based Transition diets. For pigs fed the pelleted SEW and Transition diets, pigs fed 1 and 3 lb, respectively, had better ADG and F/G for the period d 0 to 10 after weaning, better F/G for the period d 0 to 28, lower feed cost per lb of gain, and greater margin over feed than pigs fed 0.5 and 1 lb, respectively, of SEW and Transition diets. The current recommendations of providing weanling pigs 1 lb/pig SEW diet and 3 lb/pig Transition diet optimized growth and profitability in this production system.

(Key Words: Nursery Pig, Pellets, Feed Budget, Spray-dried Animal Plasma.)

Introduction

Average weaning age has increased by an average of three days in the last few years, indicating the need to re-evaluate the current feed budget used for nursery pigs. The current feed budget used for 11- to 12-lb pigs allocates 1 lb of SEW diet and 3 lb of Transition diet per pig. This may need to be modified because weaning ages and weight have increased. Recent studies also suggest that nursery pigs started on pelleted diets have greater gain and feed intake than do pigs started on meal diets. With the increase in weaning age, starting pigs straight onto the meal diets may be an option, allowing producers to manufacture diets for weanling pigs on-farm. Therefore, the objective of our study was to evaluate several feed-budget options and their effects on the growth performance of nursery pigs reared in a commercial environment.

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

Procedures

A total of 2,016 pigs (initially 12.6 lb and 18 ± 2 d of age) were used in a 28-d growth assay. Pigs were randomly sorted into one of 72 pens (36 pens of barrows and 36 pens of gilts), with 28 pigs per pen. All pigs were then weighed, and pens were allotted to treatment so all pigs within block were the same average weight. One pen of barrows and one pen of gilts consumed feed from one single fenceline feeder; therefore, the experimental unit is the combined data from the two pens. Pigs were housed in a commercial nursery in southern Minnesota. Pigs were allotted to one of six treatments with a variety of feed budgets (Tables 1 and 2): a pelleted diet with 1 lb/pig of SEW diet and 3 lb/pig of Transition diet; a pelleted diet with 0.5 lb/pig of SEW diet and 1 lb/pig of Transition diet; or a Transition meal diet with either 2.5% or 4% plasma, fed at either 2 or 4 lb/pig. After the allotted amount of feed was distributed to the pens as described in the budget, all treatments were fed 12 lb/pig of a Phase 2 meal diet, and then a Phase 3 meal diet for the duration of the trial.

Data was analyzed by using PROC MIXED in SAS, as a randomized complete-block design with pens (one barrow and one gilt) consuming feed from a single feeder as the experimental unit. Least squares means were used to determine differences between treatments, and contrast statements were used to determine differences in plasma rate, pellet versus meal, and differences between the feed budgets for the meal diets.

Results and Discussion

Pigs fed the pelleted SEW and Transition diets had improved ($P<0.05$) ADG, ADFI, and F/G compared with that of the pigs fed the meal diets from d 0 to 10 (Table 4). There was no difference ($P>0.08$) in ADG, ADFI, or F/G for the feeding period from d 10 to 21 between the pigs previously fed meal or pelleted diets. For the overall feeding period (d 0 to 28), pigs fed the pelleted SEW and Transition diets had increased ($P<0.05$) ADG, improved F/G, reduced removal rates, and increased margin over feed cost, compared with pigs fed the meal-based diets. Therefore, the response demonstrated from d 0 to 10 was carried through the overall treatment period, indicating the importance of starting pigs on feed to maximize overall growth performance. The increased feed intake of pigs fed pelleted diets probably coincides with more pigs getting started on feed earlier; this might explain the fewer pigs removed (pigs who lost weight) from the study when fed pelleted diets from d 0 to 10. Starting pigs on feed quickly will also affect long-term growth performance; the more quickly pigs are started on feed, the greater the long-term growth performance through the nursery phase, as well as through the finishing phase. These data are similar to previous data that suggest that weanling pigs started on pelleted diets have increased gain and feed intake, compared with those started on meal diets.

Pigs fed the pelleted diets with 1 and 3 lb/pig, respectively, of SEW and Transition feed had increased ($P<0.001$) ADG and F/G for the d 0 to 10 period after weaning. In addition, for the overall feeding period, pigs fed 1 and 3 lb/pig, respectively, of SEW and Transiton feed had numerically ($P<0.09$) greater ADG and improved ($P<0.001$) F/G, and were 0.7 lb heavier on d 28 than were pigs fed 0.5 and 1 lb/pig, respectively, of SEW and Transition feed. Pigs fed pelleted 1 and 3 lb/pig, respectively, consumed SEW and Transition diets for a longer duration ($P<0.001$, 11 d compared with 6 d) than did pigs fed 0.5 and 1 lb/pig; therefore, pigs consumed more spray-dried animal plasma and lactose. This indicates, even with 18-d-old pigs, the importance of starting pigs on feed and including large

amounts of both lactose and spray-dried animal plasma in these diets.

Similar to the differences demonstrated between the pelleted diets, pigs fed 4 lb/pig of Transition diet as meal had greater ADG and improved F/G, compared with that of pigs fed the meal diets with 2 lb/pig. The budget that provided 2 lb/pig of Transition diet seems to have resulted in pigs being switched too quickly to the Phase 2 diets.

From d 10 to 21, there was no difference in growth performance when pigs consumed a similar Phase 2 diet. Thus, the differences in growth performance found from d 0 to 10 were maintained through the duration of the trial. Pigs fed the pelleted diets with 1 lb/pig of SEW feed and 3 lb/pig of Transition feed had greater ADG and ADFI, lower F/G and feed cost per lb of gain, and a greater margin over feed than did pigs fed 0.5 and 1 lb/pig, respectively, (Table 5). Therefore, starting pigs on pelleted diets with a budget of 1 and 3 lb/pig for the SEW and Transition diets, respectively, provided the greatest growth performance for pigs reared in a commercial environment.

Table 1. Feed Budget, lb/pig[a]

Diet Form:	Pellet 1	Pellet 2	Meal			
Plasma, %:			2.5%		4.0%	
SEW	1	0.5	---	---	---	---
Transition	3	1	2	4	2	4
Phase 2	12	12	12	12	12	12

[a]Diets were provided via a fence-line feeder providing feed for two pens of 28 pigs each.

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

	Pellet		Meal	
Item	SEW	Transition	2.5% Plasma	4% Plasma
Corn	33.21	35.32	36.70	38.16
Soybean meal (46.5% CP)	12.11	23.02	24.90	22.00
Choice white grease	6.00	5.00	3.70	3.70
Monocalcium P (21% P)	0.45	0.90	0.68	0.68
Limestone	0.60	0.70	0.45	0.45
Salt	0.20	0.30	0.30	0.30
Vitamin and trace mineral premix	0.30	0.30	0.30	0.30
Antibiotic[b]	1.00	1.00	---	---
Zinc oxide	0.40	0.40	0.39	0.39
Kem-Gest™	---	---	0.20	0.20
L-threonine	---	0.09	0.18	0.16
Lysine HCl	0.15	0.15	0.28	0.25
DL-methionine	0.15	0.14	0.18	0.16
Spray-dried animal plasma	6.70	2.50	---	---
Appetien	---	---	2.50	4.00
Select menhaden fish meal	5.80	6.00	5.50	5.50
DeProt whey	6.25	22.50	---	---
Dairylac® 80	---	---	22.50	22.50
Spray dried whey	25.00	---	---	---
Spray-dried blood cells	1.65	1.65	1.25	1.25
Choline Cl 60%	0.04	0.04	---	---
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Total lysine, %	1.69	1.55	1.65	1.65
ME, kcal/lb	1,600	1,572	1,574	1,578
Protein, %	22.2	22.1	22.4	22.3
Ca, %	0.89	0.96	0.8	0.79
P, %	0.79	0.82	0.77	0.78
Available P, %	0.62	0.59	0.54	0.56
Lysine:calorie ratio, g/Mcal	4.78	4.47	4.75	4.74

[a]Diets were fed according to a predetermined feed budget (Table 1), and all pigs were fed 12 lb/pig of the Phase 2 diet after the allotted budget had been fed. All pigs were then fed a Phase 3 diet for the reminder of the trial.

[b]Provided 200 g/ton Neomycin sulfate and 200 g/ton oxytetracycline.

Table 3. Composition of Phase 2 and 3 Diets (As-fed Basis)[a]

Item	Phase 2	Phase 3
Corn	49.82	57.85
Soybean meal (46.5% CP)	30.32	35.22
Choice white grease	3.00	3.00
Dicalcium P (18.5% P)	1.10	1.35
Limestone	0.55	0.70
Salt	0.30	0.35
Vitamin and trace mineral premix	0.30	0.30
Antibiotic[b]	0.70	0.70
Zinc oxide	0.25	---
L-threonine	0.14	0.13
Lysine HCl	0.30	0.30
DL-methionine	0.14	0.10
Select menhaden fish meal	2.25	---
Spray-dried blood cells	0.83	---
Spray dried whey	10.00	---
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.55	1.45
ME, kcal/lb	1,536	1,546
Ca, %	0.75	0.69
P, %	0.70	0.65
Available P, %	0.41	0.33
Lysine:calorie ratio, g/Mcal	4.58	4.26

[a]All pigs were fed 12 lb/pig of the Phase 2 meal diet after the allotted budget had been fed. All pigs were then fed a Phase 3 meal diet for the reminder of the trial.
[b]Provided 140 g/ton Neomycin sulfate and 140 g/ton oxytetracycline.

Table 4. Effects of Meal Transition Diets on Growth Performance of Nursery Pigs Reared in a Commercial Environment[a]

Diet Form:	Pellet 1	Pellet 2	Meal									
Plasma, %:	6.7/2.5%	6.7/2.5%	2.5%		4%			Probability, P <				
SEW, lb/pig	1	0.5	--	--	--	--						
Transition, lb/pig	3	1	2	4	2	4	SE	Treatment	Pellet 1 vs. Pellet 2	Meal vs. Pellet	2.5% vs. 4% Plasma	Meal Budget
Day of diet switch[b]												
Trans to Phase 2	11.2	6.2	7.0	11.2	8.0	11.0	0.1	0.0001	0.0001	0.0001	0.001	0.0001
Phase 2 to 3	22.3	20.0	20.5	22.7	21.2	22.5	0.3	0.0001	0.0001	0.04	0.39	0.0001
d 0 to 5												
Initial wt, lb	12.6	12.6	12.6	12.6	12.6	12.6	0.0	0.63	0.23	0.60	0.25	0.63
ADG, lb	0.17	0.16	0.09	0.07	0.08	0.08	0.02	0.0001	0.57	0.0001	0.89	0.61
ADFI, lb	0.23	0.26	0.19	0.18	0.18	0.20	0.01	0.0001	0.09	0.0001	0.58	0.65
F/G	1.49	1.70	2.26	3.56	3.14	3.26	0.72	0.21	0.84	0.02	0.68	0.32
d 5 to 10												
ADG, lb	0.49	0.35	0.34	0.42	0.32	0.37	0.02	0.0001	0.0001	0.001	0.04	0.001
ADFI, lb	0.43	0.39	0.45	0.44	0.43	0.44	0.01	0.02	0.04	0.006	0.20	0.90
F/G	0.88	1.14	1.36	1.07	1.35	1.20	0.05	0.0001	0.001	0.0001	0.19	0.0001
d 0 to 10												
ADG, lb	0.33	0.25	0.21	0.24	0.20	0.22	0.01	0.0001	0.0001	0.0001	0.11	0.02
ADFI, lb	0.33	0.33	0.32	0.31	0.30	0.32	0.01	0.11	0.63	0.04	0.51	0.67
F/G	1.01	1.29	1.53	1.28	1.54	1.44	0.05	0.0001	0.001	0.0001	0.08	0.001
D 10 to 21												
ADG, lb	0.69	0.73	0.73	0.72	0.68	0.73	0.03	0.52	0.22	0.91	0.45	0.42
ADFI, lb	1.00	1.04	1.06	1.02	1.01	1.02	0.02	0.20	0.08	0.52	0.17	0.32
F/G	1.45	1.43	1.46	1.44	1.51	1.40	0.04	0.54	0.77	0.66	0.95	0.10
d 0 to 28												
Final wt, lb	31.5	30.8	30.2	30.6	30.2	30.7	0.2	0.007	0.05	0.001	0.99	0.07
ADG, lb	0.66	0.64	0.61	0.62	0.61	0.62	0.01	0.003	0.09	0.0002	0.98	0.19
ADFI, lb	0.89	0.89	0.88	0.88	0.87	0.89	0.01	0.65	0.97	0.41	0.71	0.54
F/G	1.34	1.39	1.45	1.41	1.43	1.43	0.01	.0001	0.01	0.0001	0.72	0.13

[a]Each value is the mean of six feeders (two pens per feeder and 28 pigs per pen). All pigs were fed the 12 lb/pig of the Phase 2 diet after the indicated amount of SEW and Transition diets had been fed.

[b]Average day after weaning that pigs had consumed their Transition feed budget and were switched to the Phase 2 diet.

Table 5. Effects on Removals, Feed Cost, and Margin Over Feed [a]

Diet Form:	Pellet 1	Pellet 2	Meal									
Plasma, %:	6.7/2.5%	6.7/2.5%	2.5%		4%			Probability, P <				
SEW, lb/pig	1	0.5	--	--	--	--						
Transition, lb/pig	3	1	2	4	2	4	SE	Treatment	Pellet 1 vs. Pellet 2	Mealvs] Pellet	2.5% vs. 4% Plasma	Meal Budget
d 0 to 28												
Removal, %	3.0%	2.1%	4.8%	5.1%	3.9%	4.5%	1.1%	0.27	0.46	0.02	0.51	0.69
Feed, $/lb gain[b]	$0.153	$0.168	$0.157	$0.164	$0.158	$0.171	$0.002	<.0001	<0.0001	0.24	0.02	<0.0001
Margin over feed[c]	$5.53	$5.06	$5.02	$4.99	$4.99	$4.87	$0.10	0.003	0.003	0.001	0.52	0.48

[a]Each value is the mean of 6 feeders (2 pens per feeder and 28 pigs per pen). All pigs were fed the 12 lb/pig of the Phase 2 after the indicated amount of SEW and Transition diets had been fed.
[b]Diet costs used were $596.50, $442.70, $360.61, $401.95, $241.12, and $161.64/ton for SEW, Pelleted Transition, 2.5% Plasma Transition, 4% Plasma Transition, Phase 2, and Phase 3, respectively.
[c]Margin over feed was calculated as d 0 to 21 gain × $.45/lb minus feed cost for d 0 to 21.

INADEQUATE DIET MIXING TIME REDUCES NURSERY PIG PERFORMANCE

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

Summary

Although the importance of thoroughly mixing diets is often emphasized, little data is available to quantify the impact of inadequate mixing on pig growth performance. Therefore, a 28-d trial was conducted to evaluate the effects of mixing time on growth performance of nursery pigs. A total of 180 weanling pigs (13.9 ± 1.8 lb BW, 21± 3 d of age) were used, with 6 pigs per pen and 6 pens per treatment. Experimental treatments consisted of mixing a diet for 0, 30, 60, 120 or 330 s in a horizontal ribbon mixer. Diets were fed in two phases (d 0 to 14 and 14 to 28), with diets in both phases containing relatively large amounts of low-inclusion ingredients such as synthetic amino acids, zinc oxide, and phytase. Diets in Phase 1 also contained 3.75% fish meal and 15% dried whey. Eight samples were collected from the mixer at the completion of the mixing time for each batch of feed to determine a coefficient of variation (CV). Each bag (50.0 lb) was labeled (first to last) and sampled to determine the degree of mixing that occurred as feed was conveyed from the mixer to the bagger. Each pen of pigs was then assigned a bag of feed. Bags were distributed in the order bagged (1, 2, 3, etc.). As feed was needed, the next chronological bag of feed was then added. Mixer CV values were 178, 38, 26, 21, and 5% for Phase 1 and 172, 79, 60, 48, and 26% for Phase 2 as mixing time increased. Bag CV values were 26, 20, 16, 11, and 7% for Phase 1 and 56, 45, 40, 33, and 12% for Phase 2 as mixing time increased, indicating the degree of mixing that takes place as feed is conveyed from the mixer to the bagger. Growth performance was improved as mixing time increased (linear, $P<0.01$) in both phases. From d 0 to 28, increasing mix time increased (linear, $P<0.01$) ADG (0.73, 0.89, 0.90, 0.94, and 1.02 for 0, 30, 60, 120, and 330 s, respectively). Increasing mixing time also improved F/G (linear, $P<0.01$; quadratic, $P<0.07$; 1.55, 1.40, 1.32, 1.33, 1.30 for 0, 30, 60, 120, and 330 s, respectively). With greater use of low-inclusion ingredients such as synthetic amino acids in swine diets, these data demonstrate that inadequate mixing reduces nursery pig performance.

(Key Words: Growth, Mixer Efficiency, Nursery Pig.)

Introduction

The importance of thoroughly mixing diets is often emphasized to swine producers, but there is little data available to demonstrate the impact of inadequate mixing on pig growth performance. Feed uniformity may have a greater impact on growth performance than in the past due to changes in genetics, diet complexity, and the increased use of low-inclusion ingredients such as synthetic amino acids, phytase, antibiotics, and concentrated vitamin and trace mineral premixes. An

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

adequately mixed batch of feed has been defined as a mixture that has a coefficient of variation (CV) of 10% or less. There is little data available to suggest that this CV value is appropriate for maximizing growth performance of pigs. Therefore, the objective of this study was to evaluate the effects of mixing time and CV on the growth performance of nursery pigs fed diets containing high concentrations of low-inclusion ingredients.

Procedures

A total of 180 weanling pigs (initially 13.9 ± 1.8 lb BW, 21± 3 d of age) were used, with 6 pigs per pen and 6 pens per treatment. Pigs were randomly allotted to pens and were blocked by weight. Experimental treatments consisted of mixing a diet for 0, 30, 60, 120, or 330 s in a 1.5-ton horizontal ribbon mixer. Diets were fed in two phases (d 0 to 14 and 14 to 28), with diets in both phases containing high concentrations of low-inclusion ingredients such as synthetic amino acids, phytase, and zinc oxide (Table 1). Diets in Phase 1 also contained 3.75% fish meal and 15% dried whey. All diets were fed in meal form and were manufactured at the Kansas State University Animal Sciences and Industry Feed Mill.

Each batch of feed (700- and 1,200-lb batches for each mixing duration in Phase 1 and Phase 2, respectively) was manufactured by following a step-by-step diet-mixing procedure. Corn was added to the mixer, and the mixer was turned on to distribute the corn across the bottom of the mixer. The mixer was then turned off for all additional ingredient additions. Soybean meal was added, followed by the remaining ingredients according to inclusion rate (largest to smallest). The micro additions were all pre-weighed into a barrel and added as a micro addition after all other ingredients. The mixer was then sampled (0 s) or turned on for the specified amount of mixing time (30, 60, 120, or 330 s). Eight samples were collected from the mixer at the completion of each mixing time for each batch of feed to determine a CV for salt by using a grain probe. The batch was then discharged from the mixer and conveyed to the bagger. The discharge time was approximately 65 s for Phase 1 and 100 s for Phase 2. The discharge time was not included in the experimental treatment mixing time. At the bagger, each bag (50 lb) was labeled (first to last) and sampled with a grain probe to determine the degree of mixing that occurred as feed was conveyed from the mixer to the bagger. The bags were assigned to a pen of pigs and distributed in the order bagged (1, 2, 3, etc.). As feed was needed, the next chronological bag of feed was then added. The feeding procedure was designed to reproduce a situation similar to how a commercial auger system may distribute feed to feeders.

Each of the five dietary treatments was analyzed for mixer efficiency CV, from the samples collected from the mixer at the conclusion of mixing and from the samples collected from each bag after discharge from the mixer, by using Quantab® chloride titrators (Environmental Test Systems, Elkhart, Indiana; Table 2). There are two mixer-efficiency CV values for each diet and for each phase of feeding. Calculation for mixer efficiency CV was conducted with 12 samples collected from the bags for Phase 1 and 22 samples collected from the bags for Phase 2. Crude protein was also analyzed on each sample collected from the bags to evaluate variability in diet CP with increased mixing time (Tables 3 and 4).

Results and Discussion

Increasing the mixing time improved mixer-efficiency CV (Table 2) and CP uniformity (Tables 3 and 4) of the sample.

Mixer-efficiency CV decreased to 7 and 12% for Phase 1 and 2, respectively, at the longest mixing time of 330 s, and CP CV decreased to 2.0 and 3.3% for Phase 1 and Phase 2, respectively. These results indicate that the same standard value of ≤10% used to measure mixer-efficiency CV may not be appropriate for measuring CP CV. Crude protein concentration was lower in the first bags collected and increased as the number of bags increased, indicating that the first bags contained the ingredients low in CP, such as corn. In both instances, an increased CV value for either the CP or mixer efficiency are strong indicators that other essential nutrients may not be incorporated uniformly in the mixture and, therefore, may not allow for optimal growth performance of nursery pigs. The optimal CV for CP seems to be ≤ 3%, whereas the standard mixer efficiency of 10% seems to be near the appropriate target value for salt.

Growth performance improved (linearly, $P<0.5$) in both phases, with the largest response occurring when mixing time was increased from 0 to 60 s. But ADG, ADFI, and F/G improved through the 330 s mixing time in both phases and for the overall trial (d 0 to 28; Table 5). There was an improvement (linear, $P<0.01$) in final BW with increased mixing time. Pigs fed the diet mixed for 330 s were heaviest at d 28, compared with pigs fed diets with the other mixing durations. The salt mixer-efficiency CV for Phases 1 and 2 were 7 and 12%, which corresponds to the longest mixing time of 330 s, and the greatest growth performance seen in the trial, indicating that a CV value (≤10) for mixer efficiency can improve growth performance of nursery pigs.

Although the greatest improvement in growth performance was from 0 to 60 s, ADG and F/G continued to improve through 330 s mixing time. The mixer-efficiency CV values for salt for the 330-s mixing time were 7 and 12% for Phases 1 and 2, respectively; therefore, the linear ($P<0.01$) improvement in ADG indicates that a smaller CV value is ideal for maximizing nursery pig growth performance and ensuring an adequate incorporation of all ingredients into the mixture.

Measuring CV of CP on collected samples may not be a good indicator of uniform mixing, or the ideal CV value may need to be 3% or less to indicate a uniform mixture. More research is needed to determine if CV of CP can be used as an indicator of mixing uniformity. With greater use of low-inclusion ingredients such as synthetic amino acids in swine diets, uniform mixing becomes more important to ensure that proper nutrients are supplied to the pig; these data demonstrate that inadequate feed mixing reduces nursery pig performance.

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

Item	d 0 to 14	d 14 to 28
Corn	52.25	65.36
Soybean meal (46.5% CP)	25.25	29.96
Monocalcium P (21% P)	1.00	1.60
Limestone	0.50	1.00
Fine mixing salt[b]	0.30	0.35
Vitamin premix	0.25	0.25
Trace mineral premix	0.15	0.15
Neo-Terramycin® 10/10	0.70	0.70
Zinc oxide	0.25	0.00
L-threonine	0.12	0.13
L-lysine HCl	0.30	0.35
DL-methionine	0.18	0.15
Menhaden fish meal	3.75	---
Spray dried whey	15.00	---
Total	100.00	100.00
Calculated analysis		
Total lysine, %	1.45	1.35
ME, kcal/lb	1,484	1,486
Protein, %	20.36	19.49
Ca, %	0.78	0.80
P, %	0.75	0.73
Available P, %	0.48	0.41
Lysine:calorie ratio, g/Mcal	4.43	4.12

[a]Dietary treatments consisted of mixing the diet for 0, 30, 60, 120, or 330 s in a horizontal ribbon mixer.
[b]Fine mixing salt was used to aid in mixer-efficiency analysis.

Table 2. Coefficient of Variation (CV) for Various Feed Mixing Durations, %[a]

	Mixing Time, s				
Item	0	30	60	120	330
d 0 to 14					
Mixer[b]	178	38	26	21	5
Bag[c]	26	20	16	11	7
d 14 to 28					
Mixer[b]	172	79	60	48	26
Bag[d]	56	45	40	33	12

[a]Quantab® chloride titrators were used to determine CV on all samples.
[b]Coefficient of variation was determined from eight samples collected from the mixer for each batch of feed.
[c]The bag CV for each mix time was determined from 12 samples (one sample collected from each bag at the bagger).
[d]The bag CV for each mix time was determined from 22 samples (one sample collected from each bag at the bagger).

Table 3. Crude Protein Analysis for Each Bag Fed, d 0 to 14[a]

	Mixing Time, s				
Bag Number	0	30	60	120	330
1	8.4	14.2	18.3	19.6	21.1
2	10.1	16.9	20.0	19.9	21.7
3	17.5	22.7	21.2	20.8	21.2
4	24.1	23.9	22.6	21.2	21.3
5	25.5	24.5	20.5	22.4	21.8
6	26.0	19.9	22.4	21.4	21.6
7	24.5	23.3	21.1	20.6	21.1
8	25.3	22.2	21.3	22.3	20.3
9	26.4	22.9	21.6	21.3	21.5
10	26.0	22.5	22.0	21.6	21.4
11	24.7	23.1	23.0	20.7	21.4
12	23.5	23.4	21.9	21.3	20.8
Mean CP	21.8	21.6	21.3	21.1	21.3
STDEV	6.3	3.1	1.3	0.8	0.4
CP CV%	29.0	14.3	6.1	4.0	2.0

[a]Each bag (50 lb) was analyzed for CP to evaluate variability in diet CP.

Table 4. Crude Protein Analysis for Each Bag Fed, d 14 to 28[a]

	Mixing Time, s				
Bag Number	0	30	60	120	330
1	11.2	12.2	12.6	14.1	18.3
2	13.0	13.8	14.0	15.5	18.7
3	17.1	15.6	14.3	16.3	20.6
4	17.5	19.4	19.4	20.4	18.8
5	18.6	20.9	22.0	21.0	20.2
6	22.1	21.5	21.8	23.2	19.5
7	21.8	21.1	22.3	21.8	20.2
8	22.3	22.5	22.1	23.5	20.2
9	20.7	22.5	23.0	22.9	20.8
10	21.1	22.7	23.9	22.3	18.9
11	22.7	22.4	23.9	18.2	20.0
12	22.7	21.7	23.2	21.9	19.9
13	20.9	23.2	22.3	22.1	20.2
14	20.1	21.4	22.3	22.8	19.8
15	19.8	21.3	21.0	22.0	19.9
16	22.4	20.9	19.8	21.3	19.0
17	22.0	19.2	21.6	17.4	19.7
18	19.9	19.6	22.6	21.4	19.7
19	20.5	20.2	16.5	20.1	20.6
20	17.5	21.6	18.0	19.9	19.9
21	20.2	20.3	20.6	20.3	20.2
22	21.8	21.6	21.0	21.5	19.8
Mean CP	19.8	20.2	20.4	20.4	19.8
STDEV	3.0	2.9	3.3	2.6	0.7
CP CV, %	15.2	14.1	16.1	12.7	3.3

[a]Each bag (50 lb) was analyzed for CP to evaluate the variability in diet CP.

Table 5. Effects of Inadequate Diet Mixing Duration on Nursery Pig Performance[ab]

	Mixing Time, s						Probability, P <	
Item	0	30	60	120	330	SE	Linear	Quadratic
d 0 to 14								
Initial wt, lb	13.9	14.0	13.9	13.9	13.9	0.74	0.47	0.79
ADG, lb	0.42	0.55	0.54	0.56	0.62	0.05	0.001	0.40
ADFI, lb	0.56	0.66	0.61	0.64	0.69	0.04	0.02	0.82
F/G	1.64	1.22	1.14	1.14	1.12	0.15	0.02	0.11
d 14 to 28								
ADG, lb	1.04	1.24	1.26	1.31	1.42	0.10	0.001	0.25
ADFI, lb	1.51	1.81	1.75	1.85	1.96	0.12	0.01	0.24
F/G	1.55	1.47	1.40	1.42	1.38	0.7	0.04	0.26
d 0 to 28								
Final wt, lb	34.3	38.9	39.1	40.2	42.5	2.7	0.001	0.51
ADG, lb	0.73	0.89	0.90	0.94	1.02	0.08	0.001	0.18
ADFI, lb	1.04	1.23	1.18	1.25	1.33	0.08	0.01	0.27
F/G	1.55	1.40	1.32	1.33	1.30	0.07	0.01	0.07

[a]A total of 180 weanling pigs (average initial BW of 13.9 ± 1.8 lb, 21± 3 d of age) with 6 pigs per pen and 6 pens per treatment.
[b]There were no cubic responses (P<0.05) observed.

LACTOSE AND SPECIALTY PROTEIN SOURCES INFLUENCE FLOW ABILITY OF NURSERY PIG DIETS

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

Summary

Two experiments were conducted to determine the effects of lactose products and specialty protein sources on feed flow ability as measured by angle of repose. Angle of repose is the maximum angle in which a pile of ingredient retains its slope. A large angle of repose represents a steeper slope and poorer flow ability. A 70:30 corn-soybean meal blend served as the base to which all specialty ingredients were added. In Experiment 1, six lactose sources were evaluated. Three sources were fine, powdered whey permeates, and the other sources were coarse-ground whey permeate, edible-grade spray-dried whey, and a crystalline lactose source. Lactose sources were added at 0, 5, 10, 20, and 30% to the corn-soybean meal blend. Angle of repose was then measured on these mixtures, as well as on the individual lactose sources. There was a lactose source × level interaction ($P<0.0001$) observed. Increasing lactose source decreased angle of repose, but the coarse whey permeate had a much greater improvement in flow ability, resulting in the interaction. In Experiment 2, five specialty protein sources were evaluated: powdered or granulated spray-dried animal plasma, powdered or granulated spray-dried blood cells, and select menhaden fish meal. Specialty protein sources were added at 0, 2.5, 5, 7.5, and 10% to the 70:30 corn-soybean meal blend. There was a specialty protein source × level interaction ($P<0.0001$) observed. As powdered animal plasma and blood cells increased, angle of repose increased, resulting in poorer flow ability. With the addition of granulated animal plasma and blood cells, angle of repose decreased, indicating better flow ability. Increasing fish meal did not influence angle of repose. These data confirm that greater flow ability is observed with granulated specialty protein or coarsely ground lactose sources.

(Key Words: Angle of Repose, Lactose, Flow Ability, Specialty Protein Sources.)

Introduction

Lactose and specialty protein sources are often included in nursery pig diets to stimulate feed intake and improve growth performance. High concentrations of these ingredients, unless pelleted, frequently increase the incidence of feed bridging in bins and feeders. Therefore, two experiments were conducted to determine the effects of different lactose sources and specialty protein sources on flow characteristics of a 70:30 corn-soybean meal diet.

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

Procedures

In Experiment 1, the objective was to evaluate the effects of increasing lactose sources on diet flow ability. Six different lactose sources were used, including three sources of fine, powdered whey permeates; a coarse-ground whey permeate, an edible-grade spray-dried whey; and crystalline lactose. The lactose sources were added at 0, 5, 10, 20, and 30% of a 70:30 corn-soybean meal blend. In Experiment 2, the objective was to evaluate the effects of increasing specialty protein sources on flow ability. The five different protein sources were powdered or granulated spray-dried animal plasma, powdered or granulated spray-dried blood cells, and select menhaden fish meal. The specialty protein sources were added at 0, 2.5, 5, 7.5, and 10% to a 70:30 corn-soybean meal blend.

The corn and soybean meal were dried for 12 h to equalize moisture content. After mixing the test ingredient with the corn:soy blend, angle of repose was measured. Angle of repose was replicated five times within each sample.

Angle of repose is defined as the maximum angle measured in degrees at which a pile of grain retains its slope. An angle-of-repose tester was constructed from 4 pieces of poly vinyl chloride (PVC). The tester is 3 inches in diameter and 36 inches tall and attached to a 3 inch PVC floor mounting. A 3-inch-diameter plate was mounted to the top of the machine, which allowed two 3-inch PVC couplers to slide up and down the long axis of the tester. To conduct the angle of repose test, a 500-g sample was placed inside the couplers at a specified height at the top of the tester. The base of the angle of repose tester was held stationary and the PVC couplers were lifted vertically, allowing the test ingredient to flow downward, resulting in a pile on top of the plate. The height of the pile was measured, and angle of repose was calculated by the equation: Angle of repose = $\tan^{-1}$ (the height of the pile divided by one half the diameter of the plate). A larger angle of repose represents a steeper slope and poorly flowing product; a low angle of repose would represent a freer flowing product. All data was analyzed by using PROC MIXED in SAS 8.1. Source and concentration were modeled, and parameter estimates were then calculated to develop regression equations. Graphs showing the modeled data were generated.

Results and Discussion

In Experiment 1, a lactose source × concentration interaction ($P<0.0001$) was observed. As percentage of all lactose sources increased, angle of repose decreased, indicating improved flow ability. The coarse-ground lactose source had the greatest decrease in angle of repose as the inclusion rates increased, therefore, having the best flow ability and resulting in the interaction. The improvement in flow ability observed with the additions of fine lactose sources is not consistent with the normal observations of poor flow ability of milk products in swine diets, Humidity and overall environment of commercial barns may play a large role in the flow ability of lactose sources. In our trial, the corn:soybean meal blend was standardized to a low moisture content, More research is needed to determine the effects of additional factors, such as humidity, on the flow ability of lactose sources.

In Experiment 2, a specialty protein source × concentration interaction ($P<0.0001$) was observed. Angle of repose increased with increasing inclusions of powdered animal plasma and blood cells, indicating poorer flow ability. The angle of repose decreased as inclusion rates of granulated animal plasma

and blood cells increased, indicating better flow ability. Increasing fish meal did not influence angle of repose.

These data confirm that specialty ingredients influence the flow ability of starter diets when fed as meal. Specialty protein and lactose sources in powder form reduce flow ability in meal diets, whereas granulated specialty protein sources and course-ground lactose sources improve flow ability.

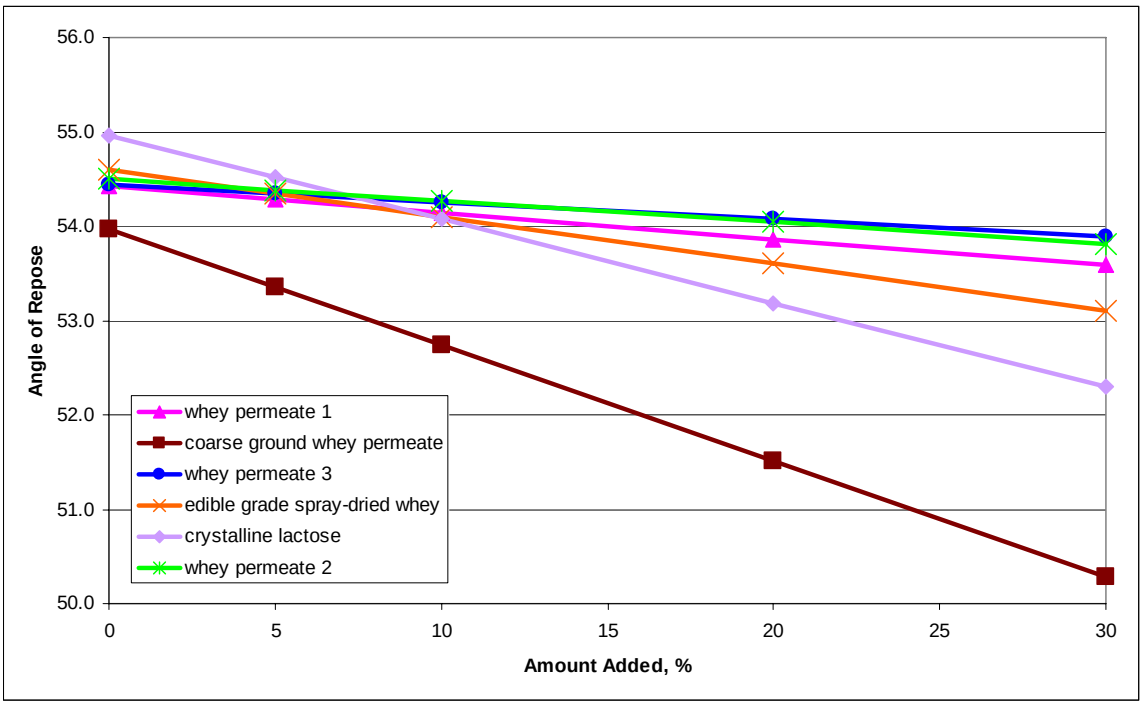


Figure 1. Effect of Lactose Sources on Flow Ability. There was a lactose source × concentration interaction ($P<0.0001$). As percentage of all lactose sources increased, angle of repose decreased, therefore improving flow ability. The coarse-ground lactose source had the greatest decrease in angle of repose as the inclusion rates increased, therefore having the best flow ability and resulting in the interaction observed.

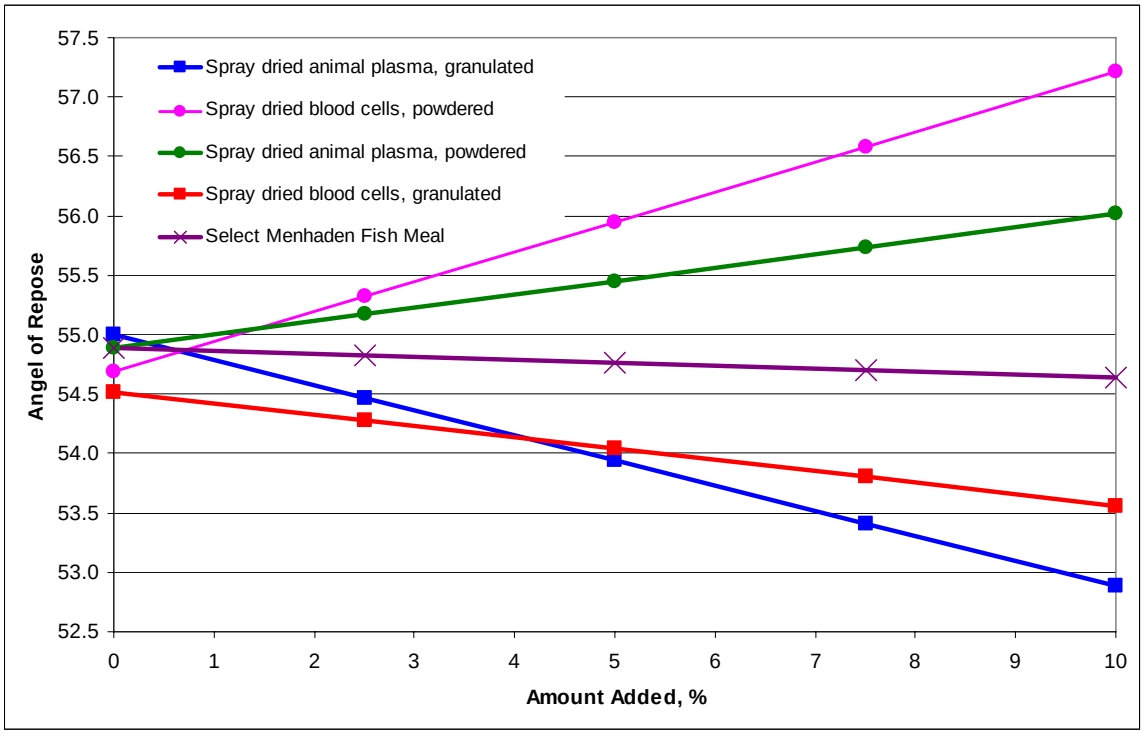


Figure 2. Effect of Specialty Protein Sources on Flow Ability. A specialty protein source × concentration interaction ($P<0.0001$). Angle of repose increased with increasing inclusions of powdered animal plasma and blood cells, therefore resulting in poorer flow ability. The angle of repose decreased as granulated animal plasma and blood cells inclusions increased, therefore resulting in a better flow ability. Increasing fish meal did not influence angle of repose.

EFFECT OF INITIAL SORTING AND AMOUNT OF ADDED FAT ON PERFORMANCE OF GROWING-FINISHING PIGS REARED IN A COMMERCIAL FACILITY[1]

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

Summary

Two studies were conducted to determine whether the amount of dietary energy fed to pigs of different weight categories influenced growth performance, market weight, and economic return in a commercial grow-finish facility. In Experiment 1, a total of 1,032 pigs with initial weight of 67.7 lb were individually weighed, fitted with electronic ear tags, and sorted into ten, 5-lb weight categories. Pigs were then allotted to pens lighter and heavier then the barn mean or to pens remixed to create a normal distribution around the mean. To complete the 2 × 3 factorial, pigs were fed corn-soybean meal diets, with or without 6% choice white grease. For the overall trial, there were no fat × weight-category interactions ($P>0.15$). Pigs fed 6% added fat tended ($P<0.07$) to have greater ADG (1.79 vs. 1.76 lb), but added fat did not affect ($P>0.15$) SD or CV of gain for the overall trial. For weight category, regardless of diet, heavy pigs grew faster ($P<0.01$, 1.83, 1.72, and 1.76 lb) than either the light or mixed pigs, respectively. In Experiment 2, 1,176 pigs with an initial weight of 77.4 lb were tagged and visually sorted into five weight categories. Pigs (28 per pen) were then allotted to pens lighter and heavier than the barn mean or remixed to create a normal distribution around the mean. To complete the 2 × 3 factorial, pigs were fed corn-soybean meal diets, with or without 6% choice white grease. For the overall trial, there were no fat × weight-category interactions ($P>0.25$). Pigs fed 6% added fat had greater ($P<0.07$) ADG, but there was no difference ($P>0.61$) in SD or CV for ADG during the overall study. For weight category, regardless of diet, heavy pigs grew faster ($P<0.02$, 1.96, 1.92, and 1.94 lb) than either the light or mixed pigs, respectively. Although no interactions existed for growth or carcass data, there was a fat × weight-category interaction ($P<0.07$) for the financial response of margin over feed cost (MOF). Heavy pigs in both studies had greater ($P<0.01$) MOF than either light or mixed pigs; when comparing 0 and 6% added fat within weight category, however, the increase in MOF was greater for light pigs fed added fat than for heavy pigs fed added fat. These studies indicate that adding 6% added fat does not increase variation within or across a population. Because adding fat to the diets of lightweight pigs improves their growth rate, dietary fat can be used selectively in the barn to increase the weight of the lightest 50% of the pigs.

(Key Words: Finishing Pig, Dietary Fat, Variation.)

---

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

[2]Food Animal Health & Management Center, College of Veterinary Medicine.

Introduction

The competitiveness of the modern swine industry dictates that feed, labor, and facilities must be used efficiently. The importance of growth rate has increased with the adoption of all-in, all-out (AIAO) technology to improve facility utilization and increase profitability. During the marketing period of AIAO finishing facilities, the normal distribution of the population of pig weights dictates that lightweight pigs will be present. Packer matrices in the United States impose large discounts for these lightweight pigs. Therefore, any technology or management technique that reduces the number of lightweight pigs will result in a higher net return. There are two methods to decrease the number of lightweight pigs without increasing days on feed. The first method is to reduce the amount of variation within the population. But reducing the amount of variation is difficult to achieve. A second method is by increasing the growth rate of the lightest pigs, thus shifting this portion of the population to heavier weights. The addition of dietary fat has been shown to increase the ADG in commercial field conditions. Thus, our objective was to determine whether adding dietary fat could be used on the lightest 50% of the population in a finishing barn to increase ADG and economic return. The second objective was to determine if adding dietary fat influenced the CV for ADG within heavy or lightweight pigs.

Procedures

General. The Kansas State University Institutional Animal Care and Use Committee approved all experimental protocols used in this study. The nutrient composition of ingredients provided by the NRC (1998) was used in diet formulation (Table 1). In Experiments 1 and 2, diets were fed in meal form and formulated to meet or exceed the NRC (1998) nutrient requirements. Amino acid percentages were greater than those previously demonstrated to maximize performance for pigs of the same genetic composition in the same facilities. Dietary treatments were fed in three phases. A constant lysine:energy ratio was maintained within each phase, with the ratios being 3.5, 2.9, and 2.4 g lysine / Mcal ME in the three phases, respectively. Both experiments were conducted in 41 ft × 250 ft barns in southwestern Minnesota. The barns contained 48 pens (10 × 18 ft). Each pen contained one 4-hole dry feeder and two cup waterers. The curtain-sided barn has a deep pit, with completely slatted floors, and operates on natural ventilation during the summer and mechanically assisted ventilation during the winter. Treatments were arranged as a 2 x 3 factorial. Main effects included diet energy density (none or 6% added fat) and pigs sorted into three weight categories.

Experiment 1. This experiment began in March 2004 with 1,232 (PIC L337 x C1050) gilts. Pigs were individually tagged with 1.2-inch round electronic identification tags (EID) with unique 15-digit code numbers. Pigs were weighed individually and sorted into pens by 5-lb weight categories. Pigs were then allotted to pens lighter and heavier than the barn mean or to pens remixed to create a normal distribution around the mean (Light, Heavy, and Mixed). There were 24 or 25 pigs per pen and 7 pens per treatment. Pens of pigs were weighed, and feed disappearance was determined, every 14 days during the entire experiment. Individual pig weights were recorded at the beginning, approximately 8 wk after the start of experiment (d 56), approximately 3 wk before conclusion (d 88), and at the conclusion of the experiment (d 109). In conjunction with the third individual weigh period, the barn was "topped" to simulate commercial production practices. The two heaviest pigs from heavy pens and the heaviest pig from mixed pens were visually selected, removed, and marketed. At the end of the experiment, pigs from each pen were individually tattooed and shipped to Swift proc-

essing plant (Worthington, MN), where standard carcass criteria (loin and fat depth, hot carcass weight, dressing percentage, lean percentage, and fat-free-lean index) were measured.

Experiment 2. This experiment started in October 2004 with 1,176 pigs (PIC L337 × 1050) gilts. Pigs were individually tagged with 1.2-inch round electronic identification tags (EID) with unique 15-digit code numbers. Pigs were then visually categorized and marked into five weight groups around the population mean (very light, light, average, heavy, and very heavy). Pigs were sorted into weight treatments with 28 pigs per pen by randomly selecting pigs within each sort category. Each weight-treatment pen contained 12 average pigs. Light pens were completed by adding 8 very light, and 8 light pigs; heavy pens were completed by adding 8 heavy and 8 very heavy pigs. For mixed pens, 4 each of very light, light, heavy, and very heavy pigs were added. Next, pigs within each weight treatment pen were individually weighed. For the duration of the experiment, pens of pigs were weighed, and feed disappearance was determined, every 14 days; individual pig weights were recorded at the beginning, approximately 8 wk after the start of experiment (d 49), approximately 3 wk before conclusion (d 81), and at the conclusion of the experiment (d 95). As in the first experiment, the two heaviest pigs from heavy pens and the heaviest pig from mixed pens were visually selected and removed to simulate topping of barns. At the end of the experiment, pigs from each pen were individually tattooed and shipped to Swift processing plant (Worthington, MN), where standard carcass criteria (loin and fat depth, hot carcass weight, dressing percentage, lean percentage, and fat-free-lean index) were measured. Because the packing plant lost 60% of the carcass data from this experiment, sort discount was calculated from the individual final weights. Final weight was converted to market weight by using a historical yield from this production system of 76.45%. The sort discount was determined by applying the weight of each pig to the weight matrix being used by the processing plant.

Statistical Analysis. Data from both experiments were analyzed as a complete randomized design with pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). Contrasts were used to determine the main affects of sorting, added fat, and their interaction on growth performance. Preplanned nonorthogonal contrasts also were used to compare the mean weight of the pens of sorted pigs (heavy and light pens combined) with that of the unsorted pens of pigs, as well as heavy vs. light by fat interaction.

Results

Experiment 1. The addition of fat to diets increased ($P<0.04$) ADG in the first two periods and tended ($P<0.08$) to increase growth for the overall study (Table 2). In addition, adding fat reduced ($P<0.01$) feed intake and improved ($P<0.01$) feed efficiency during each period. For the overall study and d 88 to 109, there was a heavy vs. light × fat interaction ($P<0.04$) for ADG. This occurred because there was an increase in ADG when fat was added to diets for light pigs but not heavy weight pigs. There also was a heavy vs. light × fat interaction ($P<0.05$) for ADFI for d 88 to 109 and the overall study. There was a greater reduction in ADFI for heavy pigs than for light pigs when fat was added to the diets. There were no interactions ($P>0.12$) of fat, sorting, and weight on feed efficiency. The addition of fat to diets increased ($P<0.03$) weight at d 88, but had no effect ($P>0.11$) on overall weight, CV of weight, or CV for ADG (Table 3). There was no difference ($P>0.42$) in backfat, fat-free lean, % lean, or loin depth between pigs fed diets with or without added fat. Adding fat increased ($P<0.02$) feed cost

per lb of gain, but had no effect on sort discount or MOF.

For initial sort, as expected, the initial weight of heavy pigs was greater than weight of light pigs; but, when combined, weights were similar to weights of mixed pigs. Pigs sorted into light or heavy pens maintained lower (P<0.02) weight CV throughout the study. Because of the interaction of fat on ADG in heavy pigs, there was a heavy vs. light × fat interaction (P<0.05) for final weight. Further evaluating the effects of sorting on weight CV, sorting pigs into light and heavy pens decreased (P<0.05) CV for weight for the overall trial, compared with the CV of mixed pigs. But sorting had no effect (P>0.30) on CV for ADG or carcass traits. Pigs sorted into heavy pens had greater (P<0.01) feed cost per lb of gain and had greater MOF. Although growth and carcass data did not show interactions, differences in the financial response were evident in MOF. Comparing added fat within initial sort category, adding 6% dietary fat decreased MOF for heavy ($95.72 vs. $94.11) and mixed ($91.13 vs. $90.48) pigs, but increased MOF for light pigs ($86.92 vs. $88.38).

For the overall 109-d trial, there were no weight category × fat interactions (P>0.44). Again there was a heavy vs. light × fat interaction (P<0.03) for ADG. This occurs because the addition of fat to diets for lightweight pigs increases ADG, but did not increase ADG for heavy pigs. This interaction was unexpected and suggested that a second study was needed.

Experiment 2. Pigs fed diets with added fat had greater (P<0.01) ADG for d 0 to 49 and overall (Table 4). Furthermore, adding fat reduced (P<0.01) ADFI and improved feed efficiency during every period and for the overall study. In contrast to Experiment 1, there was no (P>0.37) heavy vs. light × fat interaction for ADG. Similar to results of Experiment 1, Experiment 2 found that pigs sorted into heavy pens had greater (P<0.01) ADG overall, compared with that of pigs in light or mixed pens.

Unlike Experiment 1, there was no heavy vs. light × fat interaction of ADFI. Pigs in heavy pens had greater (P<0.01) ADFI than did mixed or light pigs, and there was not an interaction of added fat and sorting on feed efficiency. As in Experiment 1, lightweight pigs had a better (P<0.01) overall feed efficiency than heavy or mixed pigs had.

Adding dietary fat increased (P<0.01) weight in every period (Table 5), but adding fat had no effect (P>0.41) on CV of weight in any period or overall. Feeding pigs diets with fat did reduce (P<0.01) CV of ADG for d 49 to 81, but this response was not found (P>0.64) in other periods or for the overall trial.

For the effects of initial sorting, pigs in light or heavy pens maintained weight differences, compared with pigs in mixed pens, for the entire study. At the end of the study, there was a heavy vs. light × fat interaction (P<0.05) for final weight. Adding fat to diets for light pigs increased final weight to a greater extent than adding fat to diets for heavy pigs did. Pigs sorted by weight maintained differences in CV for weight during the entire study. There also was a heavy vs. light × fat interaction for CV of weight on d 49 (P<0.06) and d 81 (P<0.04). This occurred because adding fat to diets increased CV for heavy pigs and decreased weight CV for lightweight pigs.

A heavy vs. light × fat interaction (P<0.03) was also found for CV for ADG from d 0 to 49. Again this response occurred because CV for ADG increased when fat was added to diets for heavy pigs, whereas adding fat to diets for lightweight pigs decreased CV for ADG. The influence for sorting on CV of ADG was inconsistent, with a response

($P<0.04$) from d 0 to 49 and d 81 to 95, but no response from d 49 to 81 or for the overall trial.

In contrast to the response in Experiment 1, there was a heavy vs. light × fat interaction ($P<0.01$) for MOF. But numerical trends were similar between studies. Comparing added fat within weight category, adding 6% dietary fat decreased MOF for heavy ($96.69 vs. $95.88) and mixed ($92.56 vs. $92.29) pigs, but increased MOF for light pigs ($91.72 vs. $88.53). Looking at the effects of sort, heavy pigs had a higher ($P<0.01$) feed cost per lb of gain and had greater MOF than either light or mixed pigs ($96.28, $90.13, and $92.42, respectively).

Discussion

Lightweight pigs are a costly problem in AIAO swine production. Variation in growth is significant because it reduces the amount of product sold, increases number of days to bring lightweight pigs to market weights, and results in extra facility cost. Variation in growth within AIAO systems is caused by differences in health, genetic makeup, and social interactions. Days to market for a group of pigs is dictated by the growth rate of the lightest 50% of the pigs in the barn because they must reach a minimum weight to minimize sort discount at the processor. Thus, within a population of pigs, increasing the ADG has more value in lightweight pigs than in their heavy counterparts.

Increasing dietary energy, such as with addition of dietary fat, is one of few nutrition tools available to increase ADG for pigs fed an otherwise nutritionally adequate diet. Previous studies have shown that the addition of dietary fat to corn-soybean meal diets increases ADG. In commercial swine production, dietary energy level often limits ADG. In general, for every 1% added dietary fat, average daily gain is expected to increase 1% and feed efficiency is expected to improve approximately 2%. In our studies, adding fat in diets for light pigs increased ADG by 3.8 and 4.0% for Experiments 1 and 2, respectively. In Experiment 1, heavy pigs had a slight decrease (1.83 vs. 1.85 lb) in ADG when fed diets with added fat. This was an unexpected response, and prompted us to conduct the second study. For Experiment 2, providing fat in the diets increased ADG by 1.2% for heavy pigs. The magnitude of the response for increasing ADG by adding fat was greater for light pigs in both experiments. The increase in weight in light pigs from adding dietary fat moved a larger number of lightweight pigs closer, and into, the packer's marketing window.

For pigs heavier than the population mean, providing additional energy will increase market weight and move a larger portion of pigs out of the optimal weight range for the packer, increasing sort discounts. A secondary analysis of our data was performed to evaluate the implications of feeding the lightest 50% of the population diets with added fat while feeding diets without added fat to the heaviest 50% of the population. This population (combined) was then compared with the unsorted mixed populations that were fed diets either with or without added fat. Individual weights from these treatments in both studies were used to create a cumulative sum graph (Figure 1) to represent the portion of the population that would be at, or below, a specific weight. As the graph illustrates, adding fat to the diet for the mixed population simply shifts the population to the right, resulting in fewer pigs being lower than the desired weight range for the packer. But this shift of the curve for the mixed population also results in more pigs being heavier than the optimal weight range for the packer. If pigs would be sorted at the beginning of the finishing period, with the lightest 50% of pigs on one feed line and the heaviest 50% of pigs on another feed line, dietary fat could be fed to only the population

that needed the extra weight gain (light pigs). This situation is simulated in the combined group in Figure 1. When this approach is used, the lower end of the curve is shifted to the right because adding dietary fat increased ADG for the light pigs. The upper end of the curve is not shifted to the right because the heavy pigs would be fed the lower-energy diet without added fat. This illustrates that an initial sort, in conjunction with feeding two different dietary energy treatments, may be effective in moving a larger percentage of the pigs into the packer's ideal marketing grid.

Results from these studies show that increasing growth rate by the addition of fat to diets for the lightest 50% of the population results in a greater MOF for lightweight pigs. In our studies, however, the addition of dietary fat in heavy pigs reduced MOF. The value of the additional weight will depend on the availability of finishing space. If extra space already exists, the increase in ADG is worth only fewer days in the facility. When space is limited, increasing the ADG is worth the extra pounds sold at market. The economics of adding fat to a growing-finishing diet depend on the design of the production system, as well as the prices of corn, soybean meal, fat, and carcass price. The performance results from Experiment 2 were used to evaluate the effects of adding fat on heavy, light, and mix pigs. Using monthly historical prices for Iowa-Southern Minnesota corn, high protein soybean meal, fat, and carcass prices over a period from January 1989 until December 2003 showed that feeding fat to the lightest 50% of the populations was economically justified (maximized MOF) in all 180 months in the period (Table 6). For the heavy pigs, adding dietary fat increased MOF in only 9 of the 180 months evaluated. A major reason for the poorer economic return to dietary fat in the heavy pigs is that they were already past the optimal market weight, and extra weight gain led to greater sort discounts. If lower sort discounts are used in the analysis, such as those from Experiment 1, adding fat to diets for heavy pigs increased MOF in 146 out of 180 months evaluated. This demonstrates the importance of understanding the value of incremental increases in weight on economic return for each subpopulation of pigs.

Many producers try to minimize variation and discounts by sorting pigs into more uniform weight groups at placement into the finishing barn. Several studies have reported that sorting pigs into uniform-weight pens did not improve overall performance. Our studies also support those findings, inasmuch as the mean of pigs sorted into light and heavy pens had the same ADG as that of mixed pigs that were not sorted. In Experiment 2, there was an inconsistent response of sorting on CV for ADG. Feeding diets with added fat reduced CV of ADG for lightweight pigs in periods 0 to 49 and 81 to 95, and increased CV for heavy pigs. This effect of sorting was not seen in Experiment 1, and no explanations are readily obvious. Sorting pigs at or near time of marketing can reduce sort discounts, but pigs that remain in the facility assume greater facility cost and reduced profitability. Thus, it is important to increase ADG of lightweight pigs in conjunction with sorting.

These results show that adding 6% dietary fat to the lightest 50% of the population increased ADG and reduced the number of lightweight pigs sold. By feeding 6% dietary fat to the light pigs and removing fat for heavy pigs, producers can increase MOF more than by feeding mixed populations of heavy and light pigs. These studies also show that initial sort did not increase variation within or across a population. Furthermore, feeding pigs 6% added fat diets did not increase the CV of growth rate, compared with that of pigs fed diets without added fat.

Table 1. Composition of Diets in Experiments 1 and 2 (As-Fed Basis)[a]

	Phase 1[b]		Phase 2[c]		Phase 3[d]	
	Added Fat		Added Fat		Added Fat	
Ingredient	0%	6%	0%	6%	0%	6%
Corn	68.70	58.64	75.82	66.26	75.28	65.75
Soybean meal (46.5% CP)	28.92	32.91	22.02	25.49	22.73	26.18
Choice white grease	-	6.00	-	6.00	-	6.00
Monocalcium P (21% P)	0.73	0.85	0.60	0.75	0.50	0.58
Limestone	0.85	0.80	0.80	0.80	0.80	0.80
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.13	0.10	0.08	0.08
Trace mineral premix	0.15	0.15	0.13	0.10	0.08	0.08
Ractopamine HCl	-	-	-	-	0.03	0.03
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						
Lysine, %	1.17	1.26	0.98	1.06	1.00	1.08
Lysine:calorie, g/mcal	3.51	3.51	2.93	2.93	2.98	2.98
ME, kcal/kg	3,334	3,602	3,345	3,612	3,350	3,618
Protein, %	19.29	20.29	16.68	17.49	16.97	17.76
Calcium, %	0.58	0.59	0.51	0.55	0.50	0.52
Phosphorus, %	0.54	0.57	0.49	0.52	0.47	0.49

[a]Diet composition was calculated according to NRC (1998) composition values for all ingredients.

[b]Phase 1 diets fed d 0 to 42 in Experiment 1 and d 0 to 49 in Experiment 2.

[c]Phase 2 diets fed d 42 to 88 in Experiment 1 and d 49 to 81 in Experiment 2.

[d]Phase 3 diets fed d 88 to 109 in Experiment 1 and d 81 to 95 in Experiment 2.

Table 2. Effects of Added Fat and Initial Sort on Growth Performance in Growing-finishing Pigs, Experiment 1[a]

	Interactive Means							Main Effects							Probability, $P <$				
	6% Fat			No Fat				Fat Addition			Weight								
Item,	Heavy	Light	Mixed	Heavy	Light	Mixed	SE	6% Fat	No Fat	SE	Heavy	Light	Mixed	SE	Fat	Sort	Sort vs. Mixed	Sort vs. Mixed by Fat IntAct	Heavy vs. Light by Fat IntAct
ADG, lb																			
d 0 to 56	1.70	1.52	1.57	1.65	1.41	1.54	0.03	1.59	1.54	0.02	1.68	1.48	1.54	0.02	0.04	0.01	0.42	0.45	0.27
d 56 to 88	1.92	1.85	1.87	1.87	1.81	1.81	0.03	1.90	1.83	0.02	1.90	1.83	1.85	0.02	0.02	0.06	0.50	0.68	1.00
d 88 to 109	2.20	2.20	2.23	2.36	2.16	2.20	0.05	2.20	2.25	0.03	2.29	2.18	2.23	0.03	0.35	0.10	0.65	0.28	0.04
Overall	1.83	1.76	1.79	1.85	1.70	1.76	0.02	1.79	1.76	0.01	1.83	1.72	1.76	0.01	0.08	0.01	0.51	0.66	0.03
ADFI, lb																			
d 0 to 56	3.73	3.15	3.35	4.03	3.24	3.62	0.07	3.42	3.64	0.04	3.88	3.20	3.48	0.05	0.01	0.01	0.33	0.73	0.10
d 56 to 88	5.22	4.78	4.94	5.82	5.07	5.38	0.09	4.98	5.42	0.05	5.53	4.92	5.16	0.06	0.01	0.01	0.37	0.99	0.11
D 88 to 109	5.73	5.38	5.64	6.66	5.89	6.11	0.10	5.60	6.22	0.06	6.19	5.62	5.86	0.07	0.01	0.01	0.63	0.13	0.03
Overall	4.48	4.01	4.21	4.98	4.25	4.54	0.07	4.23	4.59	0.04	4.74	4.17	4.39	0.05	0.01	0.01	0.41	0.76	0.05
Feed/Gain																			
d 0 to 56	2.22	2.08	2.17	2.44	2.33	2.38	0.03	2.16	2.38	0.04	2.33	2.27	2.22	0.02	0.01	0.01	0.56	0.79	0.76
d 56 to 88	2.78	2.63	2.63	3.13	2.86	2.94	0.05	2.70	2.94	0.03	2.94	2.70	2.78	0.03	0.01	0.01	0.22	0.12	0.12
d 88 to 109	2.63	2.44	2.56	2.78	2.70	2.78	0.05	2.56	2.78	0.03	2.70	2.56	2.63	0.03	0.01	0.02	0.99	0.99	0.25
Overall	2.44	2.33	2.38	2.78	2.56	2.63	0.02	2.38	2.63	0.01	2.56	2.44	2.50	0.02	0.01	0.01	0.89	0.45	0.90

[a]A total of 1,032 gilts (24 or 25 pigs per pen and 7 pens per treatment) with an initial average weight of 67.7 lb.

Table 3. Effects of Added Fat and Initial Sort on Weight Variation, Carcass Traits, and Economic Value in Growing-finishing Pigs, Experiment 1[a]

	Interactive Means							Main Effects							Probability, $P <$				
	6% Fat			No Fat				Fat Addition			Weight								
Item,	Heavy	Light	Mixed	Heavy	Light	Mixed	SE	6% Fat	No Fat	SE	Heavy	Light	Mixed	SE	Fat	Sort	Sort vs. Mixed	Sort vs. Mixed by Fat IntAct	Heavy vs. Light by Fat IntAct
Wt, lb																			
d 0	76.5	59.1	67.5	76.5	59.1	67.9	0.7	67.7	67.8	0.4	76.5	59.1	67.7	0.5	0.88	0.01	0.91	0.75	0.95
d 56	172.8	145.9	156.7	171.1	140.0	156.1	2.1	158.4	155.7	1.2	172.0	142.9	156.4	1.5	0.11	0.01	0.55	0.38	0.32
d 88	234.8	205.2	217.4	232.4	198.3	214.8	2.2	219.1	215.1	1.3	233.6	201.8	216.1	1.6	0.03	0.01	0.40	0.60	0.31
d 109	274.3	251.5	262.8	277.0	244.5	258.9	2.4	262.9	260.1	1.4	275.6	248.0	260.8	1.7	0.17	0.01	0.63	0.68	0.05
Wt, CV																			
d 0	8.72	12.67	15.42	8.72	11.02	15.87	0.706	12.27	11.87	0.407	8.72	11.85	15.65	0.499	0.49	0.01	0.01	0.30	0.25
d 56	12.76	14.72	16.20	11.55	15.69	15.05	1.257	14.56	14.10	0.726	12.16	15.21	15.62	0.889	0.65	0.02	0.08	0.64	0.39
d 88	11.38	12.77	14.08	9.07	13.34	13.25	0.997	12.74	11.89	0.576	10.23	13.06	13.67	0.705	0.30	0.01	0.02	0.98	0.16
d 109	9.98	12.79	12.59	8.38	12.18	12.40	0.933	11.79	10.99	0.539	9.18	12.48	12.50	0.660	0.30	0.01	0.05	0.58	0.60
ADG, CV																			
d 0 to 56	19.75	20.35	21.23	18.61	23.68	20.09	2.184	20.44	20.79	1.261	19.18	22.02	20.66	1.544	0.85	0.44	0.97	0.56	0.31
d 56 to 88	15.21	17.11	17.33	14.52	14.41	17.35	1.312	16.55	15.43	0.758	14.86	15.76	17.34	0.928	0.30	0.18	0.08	0.45	0.45
d 88 to 109	18.99	21.75	18.60	19.06	17.74	22.47	2.526	19.78	19.76	1.458	19.02	19.75	20.54	1.786	0.99	0.84	0.60	0.19	0.42
Overall	12.89	15.18	14.14	10.83	14.54	14.48	1.236	14.07	13.28	0.713	11.86	14.86	14.31	0.874	0.44	0.05	0.38	0.43	0.57
Carcass traits																			
Back Fat (mm)	15.02	14.41	14.59	14.99	14.15	14.44	0.013	14.67	14.53	0.193	15.00	14.28	14.51	0.236	0.59	0.10	0.66	1.00	0.75
FFLI	51.53	51.35	51.58	51.63	51.30	51.53	0.153	51.49	51.48	0.089	51.58	51.32	51.55	0.109	0.98	0.20	0.46	0.80	0.63
Lean, %	57.02	57.16	57.48	56.95	57.56	57.14	0.290	57.22	57.22	0.167	56.99	57.36	57.31	0.205	0.99	0.38	0.58	0.32	0.43
Loin depth, cm	6.11	5.91	6.27	6.02	6.11	5.90	0.134	6.10	6.01	0.077	6.07	6.01	6.09	0.094	0.42	0.85	0.70	0.07	0.30
Economic value																			
FC/lb gain, $	0.172	0.163	0.163	0.168	0.159	0.163	0.001	0.168	0.163	0.001	0.168	0.159	0.163	0.001	0.02	0.01	0.82	0.46	0.82
Sort discount, $	-2.66	-2.02	-2.98	-2.47	-2.14	-2.23	0.348	-2.55	-2.28	0.201	-2.57	-2.08	-2.66	0.246	0.34	0.25	0.35	0.25	0.65
MOF[b], $	94.11	88.38	90.48	95.72	86.92	91.13	1.583	90.99	91.26	0.914	94.92	87.65	90.81	1.119	0.83	0.01	0.73	0.84	0.34

[a]A total of 1,032 gilts (24 or 25 pigs per pen and 7 pens per treatment) with an initial average weight of 67.7 lb.
[b]Margin over feed; calculated by using corn $2.16/bu, SBM $186.19, fat $13.34/cwt, carcass base price $45.39

Table 4. Effects of Added Fat and Initial Sort on Growth and Variation of Grow in Growing-finishing Pigs, Experiment 2[a]

	Interactive Means							Main Effects							Probability, *P* <				
	6% Fat			No Fat				Fat Addition			Weight								
Item,	Heavy	Light	Mixed	Heavy	Light	Mixed	SE	6% Fat	No Fat	SE	Heavy	Light	Mixed	SE	Fat	Sort	Sort vs. Mixed	Sort vs. Mixed by Fat IntAct	Heavy vs. Light by Fat IntAct
ADG, lb																			
d 0 to 49	1.90	1.83	1.87	1.83	1.74	1.79	0.02	1.87	1.79	0.01	1.85	1.79	1.83	0.02	0.01	0.01	0.89	0.81	0.40
d 49 to 81	2.09	2.12	2.09	2.07	2.05	2.05	0.04	2.09	2.05	0.02	2.09	2.07	2.07	0.03	0.16	0.96	0.80	0.83	0.77
d 81 to 95	2.31	2.05	2.14	2.25	1.98	2.09	0.10	2.18	2.12	0.06	2.27	2.03	2.12	0.07	0.43	0.04	0.75	0.88	0.99
Overall	2.01	1.96	1.98	1.94	1.87	1.92	0.02	1.98	1.92	0.01	1.96	1.92	1.94	0.01	0.01	0.02	0.91	0.89	0.37
ADFI, lb																			
d 0 to 49	4.37	3.97	4.19	4.67	4.25	4.48	0.06	4.19	4.45	0.03	4.52	4.10	4.32	0.04	0.01	0.01	0.83	0.99	0.84
d 49 to 81	5.40	5.03	5.20	5.82	5.49	5.67	0.07	5.20	5.67	0.04	5.60	5.25	5.45	0.05	0.01	0.01	0.94	0.84	0.82
d 81 to 95	6.37	5.67	5.91	6.77	6.24	6.59	0.11	6.00	6.53	0.06	6.57	5.95	6.26	0.07	0.01	0.01	0.99	0.26	0.40
Overall	5.53	4.61	5.00	5.95	5.03	5.42	0.06	5.05	5.47	0.03	5.73	4.81	5.22	0.04	0.01	0.01	0.25	0.97	0.91
Feed/Gain																			
d 0 to 49	2.33	2.17	2.22	2.56	2.44	2.50	0.03	2.22	2.50	0.02	2.44	2.27	2.33	0.02	0.01	0.01	0.93	0.67	0.30
d 49 to 81	2.56	2.38	2.44	2.86	2.70	2.78	0.06	2.44	2.78	0.04	2.70	2.50	2.56	0.04	0.01	0.01	0.78	0.52	0.75
d 81 to 95	2.78	2.78	2.78	3.03	3.13	3.13	0.11	2.78	3.13	0.06	2.86	2.94	2.94	0.07	0.01	0.86	0.75	0.86	0.67
Overall	2.44	2.33	2.38	2.78	2.63	2.70	0.03	2.38	2.70	0.01	2.56	2.44	2.50	0.02	0.01	0.01	0.68	0.83	0.28

[a]A total of 1,176 gilts (28 pigs per pen and 7 pens per treatment) with an initial average weight of 77.4 lb.

Table 5. Effects of Added Fat and Initial Sort on Weight Variation, Carcass Traits, and Economic Value in Growing-finishing Pigs, Experiment 2[a]

	Interactive Means							Main Effects							Probability, $P <$				
	6% Fat			No Fat				Fat Addition			Weight						Sort vs.	Sort vs. Mixed	Heavy vs. Light
Item,	Heavy	Light	Mixed	Heavy	Light	Mixed	SE	6% Fat	No Fat	SE	Heavy	Light	Mixed	SE	Fat	Sort	Mixed	by Fat IntAct	by Fat IntAct
Wt, lb																			
d 0	82.9	71.8	77.4	83.2	71.7	77.8	1.2	77.4	77.6	0.7	83.1	71.7	77.6	0.8	0.83	0.01	0.87	0.88	0.87
d 49	175.6	161.7	168.9	172.6	156.7	164.9	1.6	168.7	164.7	0.9	174.1	159.2	166.9	1.1	0.01	0.01	0.86	0.99	0.53
d 81	242.6	229.3	235.9	238.8	222.5	230.7	1.7	235.9	230.7	1.0	240.7	225.9	233.3	1.2	0.01	0.01	1.00	0.97	0.38
d 95	271.3	257.9	264.3	267.3	250.4	259.0	1.9	264.5	258.9	1.1	269.3	254.2	261.7	1.4	0.01	0.01	0.97	0.89	0.36
Wt, CV																			
d 0	9.99	12.08	15.88	9.33	12.56	15.85	0.751	12.65	12.58	0.434	9.66	12.32	15.86	0.531	0.91	0.01	0.01	0.96	0.46
d 49	9.30	10.37	12.92	8.18	11.87	13.12	0.691	10.86	11.06	0.399	8.74	11.12	13.02	0.488	0.73	0.01	0.01	1.00	0.06
d 81	8.69	8.69	10.95	8.02	10.39	11.05	0.551	9.44	9.82	0.318	8.36	9.54	11.00	0.390	0.41	0.01	0.01	0.66	0.04
d 95	7.47	8.67	9.65	7.23	9.78	9.78	0.479	8.60	8.93	0.276	7.35	9.22	9.71	0.338	0.41	0.01	0.01	0.71	0.17
ADG, CV																			
d 0 to 49	13.03	12.58	14.36	10.68	15.00	14.78	1.028	13.32	13.49	0.594	11.86	13.79	14.57	0.727	0.84	0.04	0.06	0.83	0.03
d 49 to 81	14.21	10.82	12.69	15.61	15.80	14.55	1.134	12.57	15.32	0.653	14.91	13.31	13.62	0.800	0.01	0.33	0.62	0.50	0.12
d 81 to 95	19.23	23.07	21.02	18.92	27.30	18.69	1.766	21.11	21.64	1.020	19.07	25.19	19.86	1.249	0.72	0.01	0.15	0.17	0.21
Overall	9.44	9.41	9.74	8.86	10.64	9.79	0.612	9.53	9.76	0.353	9.15	10.03	9.77	0.432	0.64	0.34	0.74	0.80	0.15
Economic value																			
FC/lb gain, $	0.168	0.159	0.163	0.163	0.154	0.159	0.002	0.163	0.159	0.001	0.168	0.159	0.163	0.001	0.03	0.01	0.82	0.53	0.30
Sort discount, $	-3.87	-1.66	-3.72	-2.83	-2.13	-2.71	0.563	-3.08	-2.56	0.325	-3.35	-1.90	-3.22	0.398	0.26	0.03	0.23	0.47	0.19
MOF[b], $	95.88	91.72	92.29	96.69	88.53	92.56	0.741	93.30	92.59	0.428	96.28	90.13	92.42	0.524	0.25	0.01	0.23	0.26	0.01

[a]A total of 1,176 gilts (28 pigs per pen and 7 pens per treatment) with an initial average weight of 77.4 lb.

[b]Margin over feed; calculated by using corn $2.16/bu, SBM $186.19, fat $13.34/cwt, carcass base price $45.39

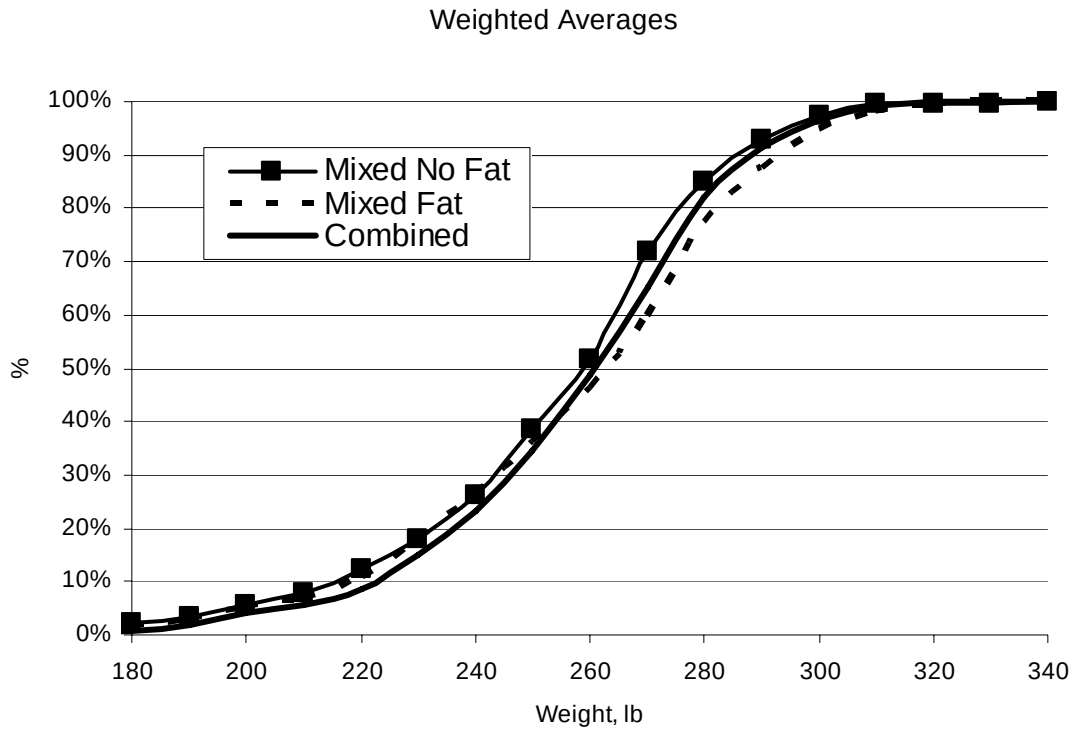


Figure 1. Cumulative-sum Graph Showing Percentage of Population at or Below Specific Weights. [a]Combined represents the light (added fat) and heavy (no added fat) treatments.

Table 6. Number of Times Added Dietary Fat had a Positive or Negative Effect on Margin Over Feed Over a 15-year Time Period[a]

	Weight		
	Light	Heavy	Mixed
Positive[b]	180	9	23
Negative[c]	0	171	157

[a]Ingredient prices from 1989 to 2003. Corn prices were from Agricultural Statistics Board (USDA) (http://www.nass.usda.gov:81/ipedb/grains.htm), soybean meal and fat prices from *Feedstuffs*, and market hog prices from Economic Research Service (http://www.ers.usda.gov/Data/sdp/view.asp?f=livestock/94006/&arc=C).
[b]Number of months that fat had a positive value for MOF over the 180-month series.
[c]Number of months that fat had a negative value for MOF over the 180-month series.

EFFECTS OF ADDED SYNTHETIC AMINO ACIDS, WITH DECREASING AMOUNTS OF FAT, ON GROWTH PERFORMANCE OF GROWING PIGS

S. S. Dritz[1], M. D. Tokach, R. D. Goodband, J. M. DeRouchey, J. L. Nelssen, and R. O. Gottlob

Summary

A total of 1,210 growing gilts (initially 102.4 lb, PIC) were used in a 28-day study in a commercial research facility to determine the effects of added synthetic amino acids, with decreasing amounts of fat, on growth performance of growing pigs. Pigs were fed one of four experimental diets based on corn-soybean meal: 1) control (3% added fat, no synthetic amino acids), 2) 2.38% added fat and high concentrations of synthetic amino acids; 3) 1.90% added fat and high concentrations of synthetic amino acids, and 4) 1.43% added fat and high concentrations of synthetic amino acids. The amounts of added fat were chosen to equalize the energy content of the diet, according to a modified ME basis, with the ME value of soybean meal being set at 95, 90, and 85% of the ME of corn in Treatments 2, 3, and 4, respectively. Overall (d 0 to 28), pigs fed diets containing high concentrations of synthetic amino acids tended to have decreased ADG ($P<0.09$) and poorer F/G ($P<0.11$) than those of pigs fed the control diet. Linear and quadratic trends for ADG, ADFI, and F/G, with decreasing amounts of added fat, were not significant. The results of this study indicate that decreasing the amount of added fat when high concentrations of synthetic amino acids are added to the diet causes a numerically reduced ADG and poorer F/G.

(Key Words: Added Fat, Amino Acids, Growing-Finishing Pig.)

Introduction

Several recent experiments have been conducted to evaluate the influence of added fat on the growth performance of growing-finishing pigs. In general, slight reductions in average daily gain and feed efficiency have been observed with decreasing amounts of added fat. In addition, because pigs are more energy deficient during the growing, or early-finishing phase, we would expect a greater response to the same reduction in dietary net energy when amounts of soybean meal are maintained. The use of high concentrations of synthetic amino acids to reduce the inclusion of soybean meal in diets has increased in recent years. Replacing soybean meal with synthetic amino acids increases the ME value of the diet, with the change in ME dependent on the energy value assigned to soybean meal relative to corn. The energy value of soybean meal has been suggested to be 85 to 95% of the value of corn, instead of the 99% suggested by NRC (1998). If the energy value of soybean meal was lower, larger amounts of added fat could be removed from the diet when high concentrations of synthetic amino acids are added to equalize the energy content in the diet. Therefore, the objective of this

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

experiment was to further characterize the value of high concentrations of synthetic amino acids in diets with decreasing amounts of added fat in diets for growing pigs.

Procedures

A total of 1,210 growing gilts (initially 102.4 lb, PIC) were placed in a commercial research facility and randomly allotted to pens upon entry to the barn. Forty pens of approximately 26 pigs per pen were blocked by initial weight and randomly allotted to one of four dietary treatments, for a total of 10 pens per treatment.

The four experimental dietary treatments were: 1) control (3% added fat, no synthetic amino acids), 2) 2.38% added fat and high concentrations of synthetic amino acids, 3) 1.90% added fat and high concentrations of synthetic amino acids, and 4) 1.43% added fat and high concentrations of synthetic amino acids. The amounts of added fat were chosen to equalize the energy content of the diet, according to modified ME basis, with the ME value of soybean meal being set at 95, 90, and 85% of the ME of corn in Treatments 2, 3, and 4, respectively. Pigs remained on the same treatments for the entire 28-day duration of the experiment. Dietary treatments were fed in meal form (Table 1) and were formulated to contain a constant lysine-to-calorie ratio with similar amounts of vitamins and minerals.

The trial was conducted in a double curtain-sided, deep-pit, commercial research finishing facility that operated on natural ventilation during the summer and mechanical ventilation during the winter. The barn had a totally slatted floor with approximately 7.2 ft^2 provided per pig. Each pen was equipped with a four-hole dry self feeder and one cup waterer. The experiment was conducted during November. Average daily gain, ADFI, and F/G were determined by weighing pigs and measuring feeders on d 0 and 28 of the experiment. 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

Overall (d 0 to 28), pigs fed the diets containing high concentrations of synthetic amino acids tended to have decreased ADG ($P<0.09$) and poorer F/G ($P<0.11$) than pigs fed the control diet had. Linear and quadratic trends for ADG, ADFI, and F/G with decreasing amounts of added fat within the synthetic amino acid diets were not significant.

Increasing concentrations of synthetic amino acids did not seem to increase the net energy of diets in this trial. The slight reduction in ADG and increase in F/G indicate that the energy values estimated by the modified ME method may have undervalued the ME value of soybean meal. It also is possible that one or more of the amino acids other than lysine became deficient when high concentrations of synthetic amino acids were added to the diet. We don't anticipate that this was a problem because all minimum ratios were maintained.

The greatest growth performance response was expected with pigs fed the diet containing the highest net energy. In this experiment, the diet that contained the highest net energy contained high concentrations of synthetic amino acids and 2.38 % fat (Treatment 2). It was surprising that pigs fed Treatment 2 had numerically lower ADG and poorer F/G than did pigs fed larger amounts of fat and lower concentrations of synthetic amino acids. Likewise, pigs fed diets containing nearly equal amounts of net energy (Treatments 1 and 4) differed greatly in growth performance (Table 2). In conclusion, the NRC ME system most accurately predicted the reduction in growth

and increase in F/G when increasing amounts of fat were removed from the diet with the inclusion of high concentrations of synthetic amino acids. Data from this trial suggest that dietary fat should not be removed when high concentrations of synthetic amino acids replace soybean meal.

Table 1. Diet Composition (As-fed Basis)

	Control	Synthetic AA		
Ingredient, % Added Fat, %:	3.00	2.38	1.9	1.43
Corn	67.02	79.40	79.92	80.44
Soybean meal (46.5% CP)	28.00	15.54	15.49	15.45
Choice white grease	3.00	2.38	1.90	1.43
Monocalcium P (21% P)	0.60	0.60	0.60	0.60
Limestone	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.08	0.08	0.08	0.08
Trace mineral premix	0.10	0.10	0.10	0.10
Isoleucine	---	0.05	0.05	0.05
L-tryptophan	---	0.03	0.03	0.03
L-threonine	---	0.15	0.15	0.15
Lysine HCl	---	0.40	0.40	0.40
DL-methionine	---	0.09	0.09	0.09
Total	100	100	100	100
Calculated analysis				
TID lysine, %	0.90	0.90	0.90	0.90
TID amino acid ratios, %				
Isoleucine:lysine ratio	78	60%	60	60
Leucine:lysine ratio	170	137	137	138
Methionine:lysine ratio	30	34	34	34
Met & Cys:lysine ratio	63	60	60	60
Threonine:lysine ratio	68	65	65	65
Tryptophan:lysine ratio	22	18	18	18
Valine:lysine ratio	88	65	65	65
Total lysine, %	1.02	0.99	0.99	0.99
ME, kcal/lb	1,577	1,570	1,560	1,550
Modified ME 95, kcal/lb[a]	1,561	1,561	1,551	1,541
Modified ME 90, kcal/lb	1,539	1,549	1,539	1,529
Modified ME 85, kcal/lb	1,517	1,537	1,527	1,517
Noblet NE, kcal/lb	1,156	1,183	1,174	1,164
CP, %	18.7	14.0	14.0	14.0
Ca, %	0.55	0.51	0.51	0.51
P, %	0.51	0.46	0.46	0.46
Available P, %	0.20	0.18	0.18	0.18
Lysine:calorie ratio, g/mcal	3.07	3.07	3.07	3.07

[a]Modified ME 95, 90, and 85 had the ME value of soybean meal at 95, 90, and 85% of the energy value of soybean meal, respectively.

Table 2. Growth Performance of Growing Pigs Fed Decreasing Amounts of Added Fat with Synthetic Amino Acids[a]

	Control	Synthetic AA			Probability, P<			
Added Fat, %:	3.00	2.38	1.90	1.43	Control vs. Synthetic	Linear[b]	Quadratic	SE
d 0 to 28								
ADG, lb	1.63	1.60	1.53	1.56	0.09	0.41	0.29	0.048
ADFI, lb	3.75	3.75	3.62	3.74	0.62	0.88	0.18	0.112
F/G	2.30	2.35	2.36	2.40	0.11	0.39	0.77	0.054

[a]Each value represents the mean of 10 pens, with approximately 26 pigs per pen. Average initial pig weight was 102.4 lb.
[b]Linear and quadratic response to change in dietary fat in the diets containing high concentrations of synthetic amino acids.

EFFECTS OF CORN SOURCE AND INCREASING LYSINE CONTENT ON GROWTH PERFORMANCE IN SWINE

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

Summary

Three studies were conducted to evaluate the effect on growth performance when NutriDense (ND) corn is used in conjunction with increasing amounts of L-lysine, threonine, and methionine. NutriDense corn is a nutritionally enhanced product containing a stacked set of traits to provide greater nutrient density than is provided by conventional yellow dent corn (YD). In Experiment 1, a total of 320 pigs (initial 40.2 lb) were blocked by weight to one of eight dietary treatments. Pigs were fed corn-soybean meal diets with either YD or ND corn and with 3, 5, 7, or 9 lb of crystalline L-lysine per ton of complete feed. Rates of methionine and threonine to lysine were balanced across all dietary treatments by the addition of DL-methionine and L-threonine. There were no corn-source × L-lysine amount interactions in this experiment. Increasing L-lysine decreased ADG (linear, $P<0.01$) and worsened F/G (linear, $P<0.01$; quadratic, $P<0.10$). There was no effect ($P>0.23$) of corn source on ADG, ADFI, or final weight, but pigs fed diets with ND corn had improved ($P<0.05$) feed efficiency.

Experiments 2 and 3 were conducted at a commercial swine research facility in southwestern Minnesota. In Experiment 2, a total of 1,189 gilts (initially 87.7 lb) were used; in Experiment 3, a total of 1,136 gilts (initially 187.3 lb) were blocked by weight in a 28-d growth assay. In both experiments, there were six dietary treatments that included either YD or ND corn and increasing amounts of L-lysine HCl (3, 6, and 9 lb/ton). In Experiment 2, there were no corn-source × L-lysine content interactions. Increasing dietary L-lysine HCl decreased ADG (linear, $P<0.01$) and worsened F/G (linear, $P<0.01$; quadratic, $P<0.08$). Feeding pigs diets with ND corn increased ($P<0.07$) ADG and improved ($P<0.01$) feed efficiency.

In Experiment 3, there was a corn source × L-lysine content interaction ($P<0.02$) for ADG and F/G. This interaction occurred because there was a greater decrease in ADG for pigs fed diets with YD corn and increasing L-lysine, compared with ADG of pigs fed diets with ND corn. No other interactions were observed ($P>0.53$). Increasing L-lysine decreased ADG (quadratic, $P<0.01$) and worsened F/G (quadratic, $P<0.01$). Feeding pigs diets with ND corn increased ($P<0.01$) ADG and improved ($P<0.01$) F/G, but had no effect on ADFI.

The use of ND corn in swine diets will reduce the amount of threonine and methionine needed when high concentrations of crystalline L-lysine are used in corn-soybean meal diets. Also, because ND corn has 34% more

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

tryptophan than typical YD corn does, higher concentrations of L-lysine, in conjunction with threonine and methionine, can be used before tryptophan becomes the dietary limiting amino acid. These studies indicate that the use of ND corn can reduce the need for threonine and methionine supplementation when supplementing with more than 0.15% L-lysine HCl.

(Key Words: L-lysine, Pigs, Yellow Dent Corn.)

Introduction

NutriDense (ND) corn is nutritionally enhanced with a stacked set of traits to provide greater nutrient density than is provided by conventional yellow dent corn (YD). Specifically, it contains approximately 23% more lysine, 19% more sulfur amino acids, 18% more threonine, and almost 34% more tryptophan than YD corn contains. Feeding trials at Kansas State University indicated that the energy value of NutriDense corn was approximately 5% greater than the energy density of yellow dent corn. Because ND corn contains greater amounts of amino acids, inclusion of ND corn in the diet can decrease soybean meal use and change the amino acid balance, which should decrease the need for secondary amino acids when high concentrations of crystalline L-lysine are used.

Recent reductions in the price of L-threonine have made it feasible to add L-threonine and DL-methionine with L-lysine to further reduce the soybean meal content in diets based on corn and soybean meal. Tryptophan becomes the next limiting amino acid when high concentrations of these three amino acids are used. Because tryptophan is increased to a greater extent than other amino acids in NutriDense corn, there is the possibility that larger amounts of crystalline L-lysine could be used in NutriDense diets than in diets with yellow dent corn before pig performance is reduced.

The objective of these studies was to evaluate the effects of replacing soybean meal with crystalline lysine, threonine, and methionine in diets containing yellow dent corn or NutriDense corn on growth performance of nursery, growing, and finishing pigs.

Procedures

All procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. All three experiments were arranged as factorials, with two corn sources (ND or YD) and either four (3, 5, 7, and 9 lb/ton; Experiment 1) or three (3, 6, and 9 lb/ton; Experiments 2 and 3) rates of L-lysine HCl replacing soybean meal in the diet. L-threonine and DL-methionine were also added to the diet to maintain minimum ratios for these amino acids Nutrient values for ND corn were provided by Exseed Genetics (Table 1); nutrient values for YD and true ileal-digestible (TID) amino acid values were from NRC (1998). All experimental diets were balanced to maintain a constant TID threonine-to-lysine ratio, TID sulfur amino acid (TSAA)-to-lysine ratio, TID lysine-to-calorie ratio, and Ca and P concentrations within each trial.

In Experiment 1, a total of 320 pigs (PIC 337 × C22 initially 40.2 lb) were used in a 17-d growth assay. Pigs were blocked by weight and were allotted to one of eight treatments. There were five pigs per pen and eight 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 waterer to provide *ad libitum* access to feed and water (Table 2). Pigs were weighed, and feed disap-

pearance was measured, on d 7, 14, and 17 to determine ADG, ADFI, and feed efficiency.

Experiments 2 and 3 were conducted at a commercial swine research facility in southwestern Minnesota. The facility has 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.

In Experiment 2, a total of 1,189 gilts (PIC 337 × C22, initially 87.7 lb) were blocked by weight in a 28-d growth assay. Pigs were randomly allotted to one of six dietary treatments in a complete, randomized design. Each pen contained approximately 28 ± 1 pigs per pen and seven replicates (pens) per treatment, with number of pigs per pen balanced across treatment. Experimental diets were based on corn and soybean meal and were fed in meal form (Table 3).

In Experiment 3, a total of 1,136 gilts (PIC 337 × C22, initially 187.3 lb) were blocked by weight in a 28-d growth assay. Pigs were randomly allotted to one of six dietary treatments in a complete, randomized design. Each pen contained approximately 27 ± 1 pigs per pen and seven replicates (pens) per treatment, with number of pigs per pen balanced across treatment. Experimental diets were based on corn and soybean meal and were fed for 28 d in meal form (Table 4).

Data from all three experiments were analyzed by using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a randomized complete-block design in the nursery study and a completely randomized design for the finishing studies, with pen as the experimental unit in all studies. After testing for interactions between corn source and lysine concentration, linear and quadratic polynomial contrasts were used to determine the effects of increasing rates of lysine. Single-degree-of-freedom contrasts were used to determine differences between corn sources.

Results and Discussion

In Experiment 1, there were no corn-source × L-lysine rate interactions for the overall nursery study (Table 5). Increasing L-lysine decreased ADG (linear, $P<0.01$; Table 6). There was no effect ($P>0.28$) of increasing L-lysine on ADFI, but increasing L-lysine worsened F/G (linear, $P<0.01$). The largest change in F/G occurred between the 3- and 5-lb/ton additions of L-lysine HCl. Increasing dietary L-lysine also reduced (linear, $P<0.01$) final weight. There was no effect ($P>0.23$) of corn source on ADG, ADFI, or final weight, but nursery pigs fed diets with ND corn had improved ($P < 0.05$) feed efficiency.

During Experiment 2, there were no corn-source × L-lysine interactions for the overall study (Table 7). Increasing dietary L-lysine HCl decreased ADG (linear, $P<0.01$) and worsened F/G (linear, $P<0.01$; quadratic, $P < 0.08$; Table 8). There was no effect of L-lysine content on ADFI or final weight. Feeding growing pigs diets with ND corn increased ($P<0.07$) ADG and improved ($P < 0.01$) feed efficiency.

In Experiment 3, there was a corn-source × L-lysine content interaction ($P<0.02$) for ADG and F/G for the overall finishing study (Table 9). This interaction occurred because there was a greater decrease in ADG for pigs fed diets with YD corn with increasing L-

lysine than for pigs fed diets with ND corn. No other interactions were observed ($P>0.53$).

Increasing L-lysine decreased ADG (quadratic, $P<0.01$) and worsened F/G (quadratic, $P<0.01$). Increasing L-lysine also decreased (linear, $P<0.01$) final pig weight. Feeding pigs diets with ND corn increased ($P<0.01$) ADG and improved ($P<0.01$) feed efficiency, but had no effect on ADFI.

Results from these studies agree with other studies at Kansas State University in which pigs fed diets with ND corn had improved performance, compared with that of pigs fed diets with YD corn. Previous studies have shown increased ADG and improvements in feed efficiency when ND corn replaced YD corn in swine diets that were balanced on an equal lysine-to-calorie ratio, due to the increased dietary energy density provided by the ND.

In corn-based swine diets, replacing soybean meal with increasing amounts of L-lysine, threonine, methionine, and tryptophan has been shown to maintain growth performance. The negative responses in our trials were likely due to a deficiency in tryptophan in diets when high concentrations of crystalline L-lysine were added to the diet. In Experiment 3, for example, with a 9 lb/ton inclusion of L-lysine, the TID tryptophan-to-lysine ratio was only 11% for YD corn; this is well below the 18% recommended by the NRC (1998). By simply using ND corn, however, which has 34% more tryptophan, the TID tryptophan-to-lysine ratio increases to 13%.

The use of ND corn in swine diets will reduce the amount of threonine and methionine needed when high concentrations of crystalline L-lysine are used. In addition, because ND corn has 34% more tryptophan than typical YD corn does, higher concentrations of L-lysine, in conjunction with threonine and methionine, can be used before tryptophan becomes the dietary limiting amino acid. These studies indicate that the use of ND corn can reduce the need for threonine and methionine supplementation when supplementing with more than 0.15% L-lysine HCl.

Table 1. Nutrient Composition of Corn Sources (As-fed Basis)

Item	Yellow Dent Corn[a]	NutriDense Corn[b]
Lysine, %	0.26	0.32
Isoleucine, %	0.28	0.41
Leucine, %	0.99	1.35
Methionine, %	0.17	0.21
Met & Cys, %	0.36	0.43
Threonine, %	0.29	0.34
Tryptophan, %	0.06	0.08
Valine, %	0.39	0.55
ME, kcal/kg	1,551	1,630
CP, %	8.50	10.00
Ca, %	0.03	0.03
P, %	0.28	0.32
Available P, %	0.04	0.13

[a]Values are from NRC (1998).
[b]Values were provided by Exceed Genetics.

Table 2. Experimental Diets, Experiment 1 (As-fed-Basis)

	YD[a]	ND[a]	YD	ND	YD	ND	YD	ND
Lysine, lb/ton:	3	3	5	5	7	7	9	9
Ingredient, %								
Corn	65.28	---	68.17	---	71.05	---	73.90	---
NutriDense corn	---	65.10	---	67.95	---	70.80	---	73.65
Soybean meal (46.5% CP)	31.27	31.55	28.15	28.48	25.04	25.41	21.96	22.30
Monocalcium P (21% P)	1.71	1.60	1.77	1.65	1.83	1.70	1.89	1.75
Limestone	1.00	1.05	1.00	1.05	1.00	1.05	1.00	1.05
Salt	0.35	0.35	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	0.08	0.08
Trace mineral premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
L-Threonine	0.03	0.02	0.07	0.07	0.12	0.11	0.16	0.15
Lysine HCl	0.15	0.15	0.25	0.25	0.35	0.35	0.45	0.45
DL-methionine	0.06	0.04	0.09	0.07	0.12	0.10	0.15	0.13
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition								
Lysine, %	1.23	1.28	1.22	1.27	1.22	1.27	1.21	1.26
ME, kcal/lb	1,497	1,549	1,497	1,551	1,498	1,554	1,498	1,557
Protein, %	20.09	21.18	18.89	20.04	17.68	18.89	16.49	17.74
Ca, %	0.82	0.82	0.82	0.82	0.82	0.82	0.83	0.82
P, %	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
True digestible amino acids								
TID lysine:ME, g/Mcal	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
Lysine, %	1.10	1.14	1.10	1.14	1.10	1.14	1.10	1.14
Isoleucine:lysine, %	0.69	0.74	0.64	0.69	0.60	0.65	0.55	0.60
Leucine:lysine, %	1.47	1.61	1.40	1.55	1.33	1.49	1.26	1.44
Methionine:lysine, %	0.32	0.31	0.33	0.33	0.35	0.34	0.36	0.35
Met & Cys:lysine , %	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Threonine:lysine , %	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Tryptophan:lysine, %	0.20	0.20	0.18	0.19	0.17	0.17	0.15	0.16
Valine:lysine, %	0.77	0.83	0.72	0.78	0.67	0.74	0.63	0.70

[a]YD: yellow dent corn; ND: NutriDense corn.

Table 3. Experimental Diets, Experiment 2 (As-fed Basis)

	YD[a]	ND[a]	YD	ND	YD	ND
Lysine, lb/ton:	3	3	6	6	9	9
Ingredient, %						
Corn	73.77	---	78.09	---	82.39	---
NutriDense corn	---	73.85	---	78.15	---	82.50
Soybean meal (46.5% CP)	23.85	23.87	19.18	19.21	14.54	14.55
Monocalcium P (21% P)	0.70	0.58	0.80	0.68	0.88	0.76
Limestone	0.85	0.93	0.85	0.92	0.84	0.92
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
L-threonine	0.01	---	0.08	0.06	0.14	0.13
Lysine HCl	0.15	0.15	0.30	0.30	0.45	0.45
DL-methionine	0.02	---	0.06	0.04	0.11	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Lysine, %	1.03	1.08	1.02	1.07	1.01	1.06
ME, kcal/lb	1,514	1,572	1,514	1,576	1,515	1,580
Protein, %	17.36	18.48	15.56	16.75	13.76	15.01
Ca, %	0.56	0.56	0.56	0.56	0.56	0.56
P, %	0.52	0.52	0.52	0.52	0.52	0.52
True digestible amino acids						
TID lysine:ME, g/Mcal	2.74	2.74	2.74	2.74	2.74	2.74
Lysine, %	0.92	0.95	0.92	0.95	0.92	0.95
Isoleucine:lysine, %	0.70	0.76	0.61	0.68	0.52	0.60
Leucine:lysine, %	1.58	1.78	1.46	1.68	1.34	1.57
Methionine:lysine, %	0.30	0.30	0.32	0.31	0.35	0.33
Met & Cys:lysine, %	0.60	0.61	0.60	0.60	0.60	0.60
Threonine:lysine, %	0.62	0.62	0.62	0.62	0.62	0.62
Tryptophan:lysine, %	0.19	0.20	0.17	0.17	0.14	0.15
Valine:lysine, %	0.79	0.87	0.71	0.79	0.62	0.72

[a]YD: yellow dent corn; ND: NutriDense corn.

Table 4. Experimental Diets, Experiment 3 (As-fed Basis)

Lysine, lb/ton:	YD[a] 3	ND[a] 3	YD 6	ND 6	YD 9	ND 9
Ingredient, %						
Corn	84.21	---	88.57	---	92.88	---
NutriDense corn	---	84.65	---	89.10	--	93.45
Soybean meal (46.5% CP)	13.68	13.28	9.00	8.58	4.33	3.88
Monocalcium P (21% P)	0.65	0.53	0.75	0.60	0.85	0.70
Limestone	0.80	0.88	0.80	0.87	0.80	0.88
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
L-threonine	0.01	---	0.08	0.07	0.14	0.13
Lysine HCl	0.15	0.15	0.30	0.30	0.45	0.45
DL-methionine	---	---	---	---	0.05	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Lysine, %	0.75	0.79	0.74	0.78	0.73	0.77
ME, kcal/lb	1,519	1,587	1,519	1,591	1,520	1,594
Protein, %	13.52	14.64	11.72	12.90	9.91	11.15
Ca, %	0.50	0.50	0.50	0.50	0.50	0.50
P, %	0.47	0.47	0.47	0.47	0.47	0.47
True digestible amino acids						
TID lysine:ME, g/Mcal	1.97	1.97	1.97	1.97	1.97	1.97
Lysine, %	0.66	0.69	0.66	0.69	0.66	0.69
Isoleucine:lysine, %	0.71	0.81	0.59	0.70	0.47	0.59
Leucine:lysine, %	1.84	2.15	1.67	2.00	1.50	1.86
Methionine:lysine, %	0.32	0.35	0.29	0.32	0.33	0.31
Met & Cys:lysine, %	0.66	0.71	0.60	0.64	0.60	0.60
Threonine:lysine, %	0.65	0.65	0.65	0.65	0.65	0.65
Tryptophan:lysine, %	0.19	0.20	0.15	0.16	0.11	0.12
Valine:lysine, %	0.85	0.97	0.73	0.86	0.61	0.76

[a]YD: yellow dent corn; ND: NutriDense corn.

Table 5. Interactive Means of Corn Source and Lysine Content on Growth Performance[a]

	NutriDense Corn				Yellow Dent Corn					Probability, *P* <
Lysine, lb/ton:	3	5	7	9	3	5	7	9	SE	Source × Concentration
Item										
Overall ADG, lb	1.57	1.54	1.45	1.45	1.55	1.47	1.47	1.44	0.038	0.51
Overall ADFI, lb	2.62	2.63	2.50	2.56	2.62	2.60	2.67	2.50	0.066	0.13
Overall F/G	1.67	1.70	1.72	1.77	1.70	1.77	1.82	1.74	0.034	0.17
Initial wt, lb	40.3	40.2	40.3	40.3	40.2	40.2	40.2	40.3	1.51	0.56
Final wt, lb	68.6	68.0	66.4	66.4	68.1	66.8	66.7	66.1	1.77	0.54

[a]A total of 320 pigs with an average initial weight of 40.2 lb were used in this experiment.

Table 6. Main Effects of Corn Source and Lysine Content on Growth Performance[a]

	Corn Source[b]			Lysine Concentrations, lb/ton					Probability, *P* <			
Item	ND	YD	SE	3	5	7	9	SE	Source	Concentration	Linear	Quad.
Overall ADG, lb	1.50	1.48	0.029	1.56	1.51	1.46	1.44	0.032	0.28	0.01	0.01	0.43
Overall ADFI, lb	2.58	2.60	0.050	2.62	2.61	2.59	2.53	0.056	0.60	0.28	0.06	0.56
Overall F/G	1.72	1.76	0.022	1.68	1.74	1.77	1.76	0.026	0.05	0.01	0.01	0.10
Initial Wt, lb	40.3	40.2	1.514	40.2	40.2	40.2	40.3	1.514	0.19	0.33	0.18	0.21
Final Wt, lb	67.3	66.9	1.710	68.3	67.4	66.5	66.2	1.729	0.23	0.01	0.01	0.37

[a]A total of 320 pigs with an average initial weight of 40.2 lb were used in this experiment.
[b]YD: yellow dent corn; ND: NutriDense corn.

Table 7. Interactive Means of Corn Source and Lysine Content on Growth Performance of Grower Pigs Reared in a Commercial Facility[a]

	NutriDense Corn			Yellow Dent Corn				Probability, *P* <
Lysine, lb/ton:	3	6	9	3	6	9	SE	Source × Concentration
Item								
Overall ADG, lb	1.92	1.96	1.85	1.92	1.86	1.74	0.047	0.43
Overall ADFI, lb	4.38	4.47	4.38	4.43	4.37	4.38	0.087	0.68
Overall F/G	2.29	2.28	2.38	2.31	2.36	2.52	0.034	0.21
Initial wt, lb	87.1	87.9	87.9	87.4	87.9	87.9	1.658	0.99
Final wt. lb	142.0	142.8	140.0	140.6	140.5	137.1	2.401	0.77

[a]A total of 1,189 pigs with an average initial weight of 87.7 lb were used in this experiment.

Table 8. Main Effects of Corn Source and Lysine Content on Growth Performance of Grower Pigs Reared in a Commercial Facility[a].

	Corn Source[b]			Lysine Concentration, lb/ton				Probability, *P* <			
Item	ND	YD	SE	3	6	9	SE	Source	Concentration	Linear	Quad
Overall ADG, lb	1.91	1.84	0.027	1.91	1.91	1.80	0.033	0.07	0.02	0.01	0.19
Overall ADFI, lb	4.41	4.39	0.050	4.41	4.42	4.38	0.062	0.78	0.90	0.75	0.75
Overall F/G	2.31	2.40	0.019	2.30	2.32	2.45	0.024	0.01	0.01	0.01	0.08
Initial wt, lb	87.7	87.7	0.958	87.3	87.9	87.9	1.173	0.93	0.91	0.72	0.81
Final wt. lb	141.4	139.6	1.387	141.4	141.8	138.2	1.698	0.36	0.27	0.18	0.34

[a]A total of 1,189 pigs with an average initial weight of 87.7 lb were used in this experiment.
[b]YD: yellow dent corn; ND: NutriDense corn.

Table 9. Interactive Means of Corn Source and Lysine Content on Growth Performance of Finishing Pigs Reared in a Commercial Facility[a]

	NutriDense Corn			Yellow Dent Corn				Probability, *P* <
Lysine, lb/ton:	3	6	9	3	6	9	SE	Source × Concentrations
Item								
Overall ADG, lb	1.81	1.76	1.39	1.82	1.70	1.15	0.044	0.02
Overall ADFI, lb	5.72	5.68	5.21	5.73	5.48	5.07	0.095	0.53
Overall F/G	3.17	3.23	3.77	3.15	3.23	4.42	0.072	0.01
Initial wt, lb	187.4	187.3	187.3	187.3	187.4	187.4	3.286	0.99
Final wt, lb	238.0	237.4	226.3	238.4	234.6	219.6	3.333	0.57

[a]A total of 1,189 pigs with an average initial weight of 87.7 lb were used in this experiment.

Table 10. Main Effects of Corn Source and Lysine Content on Growth Performance of Finishing Pigs Reared in a Commercial Facility[a]

	Corn Source[b]			Lysine Concentration, lb/ton				Probability, *P* <			
Item	ND	YD	SE	3	6	9	SE	Source	Concentration	Linear	Quad
Overall ADG, lb	1.65	1.56	0.026	1.82	1.73	1.27	0.031	0.01	0.01	0.01	0.01
Overall ADFI, lb	5.54	5.43	0.055	5.72	5.58	5.14	0.067	0.01	0.16	0.01	0.08
Overall F/G	3.39	3.60	0.041	3.16	3.23	4.10	0.051	0.01	0.01	0.01	0.01
Initial wt, lb	187.3	187.4	1.897	187.3	187.3	187.4	2.323	0.98	1.00	0.99	0.99
Final wt, lb	233.9	230.9	1.924	238.2	236.0	222.9	2.357	0.27	0.01	0.01	0.07

[a]A total of 1,136 pigs with an average initial wt of 187.3 lb were used in this experiment.
[b]YD: yellow dent corn; ND: NutriDense corn.

ADDING DRIED DISTILLERS GRAINS TO SWINE DIETS AFFECTS FEED PREFERENCE

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

Summary

Three studies were conducted to evaluate the effects of dried distillers grains with solubles (DDGS) on feed intake in growing pigs. In all experiments, pigs were housed in 10.5 × 10.3 ft pens with four 1-hole feeders in each pen to allow pigs to choose from four dietary treatments. In Experiment 1, we evaluated the influence of DDGS drying method on palatability of DDGS. Diets were a control corn soybean-meal diet or a corn soybean-meal diet with 30% DDGS from one of two drying techniques (plant dried, hand dried, or not dried). Overall, ADFI was less (P<0.05) for all DDGS drying methods than for the corn-soybean control. For Experiment 2, we compared the influence of DDGS grain source on feed intake. We compared differences between a corn-soybean meal diet and corn-soybean meal diets with 30% DDGS from two corn facilities or one milo facility. Overall, adding 30% DDGS from all sources reduced (P<0.05) ADFI below that of corn-soybean meal diets. In Experiment 3, we used gas chromatography/mass spectrometry (GC/MS) to identify compounds found in DDGS sources from Experiment 2 to determine if any specific compounds are responsible for negative effects on feed intake. We added Furfural, γ-Butyrolactone, and Phenyl ethyl alcohol to corn-soybean meal diets at twice the concentration found in diet with 30% DDGS. We fed a control corn soybean-meal diet or corn soybean-meal with 20 ppm of each compound per ton of complete feed. The addition of each individual compound had no effect (P>0.55) on feed intake. These studies illustrate that pigs prefer corn-soybean diets to diets containing DDGS. The decrease in palatability seems to increase with increasing amounts of dried distiller grains. Although the nutrient content of DDGS make it an attractive ingredient for swine diets, palatability problems may affect pig performance, even when DDGS is included at low rates in the diet.

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

Introduction

Studies have shown that distillers dried grains with solubles (DDGS) has larger nutrient values than previously reported by the NRC (1998). These studies have shown that the ME of DDGS is similar to the ME of corn. With an increase in the number of new ethanol plants, which produce DDGS as a co-product, the availability and attractiveness for use of DDGS swine diets also has increased. Because of the low lysine and high fiber content, compared with other ingredients typically fed to pigs, DDGS traditionally has been widely fed to ruminants. New processing techniques and better quality control may have lead to a better and more consistent nutrient profile of DDGS.

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

Several growth studies have shown that feed intake is less for pigs fed diets containing DDGS, compared with that of pigs fed diets based on corn soybean meal. Many production systems and feed companies that currently use DDGS in diet formulations limit the inclusion to less than 15% of the diet. Higher concentrations are seldom used because of reductions in feed intake. Thus, the rate of inclusion for DDGS in swine diets may be limited due to palatability problems. In the 2004 Swine Day Report of Progress, we reported that increasing amounts of DDGS in the diet caused a linear reduction in feed preference, and that the decreased palatability could not be overcome by including a feed flavor in the diet. The objective of these studies was to further evaluate the effects of source of DDGS on feed intake in growing pigs.

Procedures

General. The nutrient compositions of ingredients as provided by NRC (1998) were used in diet formulation, except for compositions of DDGS sources, which were determined by laboratory analysis (Table 1). All experiments were conducted at the Kansas State University Swine Teaching and Research Facility. Each pen was 10.5 × 10.3 ft, with completely slatted flooring, and contained two nipple waterers. Environmental temperature was maintained by using mechanically assisted ventilation and heaters. Four individual 1-hole self feeders (Pride of the Farm, Houghton, IA) allowed four treatment diets to be available at all times in each pen. Feeders were rotated clockwise one position every morning and evening for the entire length of each study. Feeder weights were obtained every 7 d to determine ADFI; pig weights were taken at the beginning and conclusion of the trials for calculation of growth performance.

Experiment 1. The process of drying distiller's grains has improved in recent years with development of new technology and dryer design. But dried grains can still remain in the dryer for extended periods of time and also can encounter very high temperatures. During the drying process, various volatile organic compounds are released or combined to generate various flavor components. These drying conditions may create an undesirable flavor for swine. Therefore, the purpose of this study is to evaluate different drying techniques on palatability of DDGS.

A total of 187 pigs (PIC L327 x 1050) with an initial weight of 49.4 ± 1.8 lb with four pens of barrows and gilts each and 25 pigs per pen and contained four feeders. Treatments were a control corn soybean-meal diet, corn soybean-meal with 30% DDGS from one of two drying techniques, and a fourth treatment using undried, wet product. All DDGS used in this study originated from the same batch of DDGS from a single, new dry-grind ethanol plant (Source 6). Drying techniques included plant-dried DDGS from a plant which used two drum dryers (*ICM*, Wichita, KS) and a temperature of 828°F. A second drying treatment consisted of obtaining wet DDGS from the same batch, taking it to the KSU Animal Science feed mill, and drying it in Model 982a rotary cooler (California Pellet Mill (CPM), Crawfordsville, IN). The wet distillers grain was cycled fourteen times through the cooler with indirect heat, providing an average temperature of 144°F during the process and resulting in product dried to 82.8% DM. The diets were balanced for the same amount of DDGS dry matter, total Ca, P, and lysine (Table 2).

Experiment 2. We conducted a 19-d study to evaluate feed intake when DDGS was added at 30% to corn-soybean meal diets from

three different sources. Corn DDGS was obtained from two new Midwestern dry-grind ethanol facilities within a three-week period. In addition, we wanted to measure the differences in feed intake between corn and milo DDGS diets. Milo DDGS (Source 7) was obtained from an ethanol plant that used milo as grain stock for ethanol production. We used 112 pigs (PIC L327 x 1050) with an initial weight of 69.9 ± 1.5 lb to determine if feed intake was different between a corn-soybean meal diet (Table 3) and corn-soybean meal diets with 30% DDGS from one of three different sources (Source 1, 6, and 7). There were 7 pens with 16 pigs per pen.

Experiment 3. Because of differences in intake between DDGS sources in Experiment 2, we wanted to identify specific compounds within each source that may contribute to decreased feed intake. Therefore, samples from Experiment 2 and other DDGS sources were analyzed by using gas chromatography/mass spectrometry (GC/MS) analysis to identify and quantify compounds within each DDGS source.

Our hypothesis was that these compounds may be responsible for the off flavor or taste that pigs experience when consuming diets with DDGS. Because of the trend of decreasing intake from Sources 1, 6, and 7, we plotted the percentage intake of each source from the control total feed intake within the pen. Using the results from the GC/MS analysis, we also plotted the concentration of each compound as a percentage of the total compounds present in each DDGS sample. Plotting both percentage feed intake for each source and compounds from each source on same graph revealed that three compounds were common between all samples and followed a general trend that may be correlated with depression in feed intake (Figure 1). From this analysis, we selected the three compounds (Furfural, γ-Butyrolactone, and Phenyl ethyl alcohol) for evaluation of their effects on feed intake when added to a control corn-soybean meal diet at twice the concentration that would be found in a diet with 30% DDGS. Furfural is an aldehyde that commercially is obtained by distilling acid-digested corn cobs, oat hulls, rice hulls, or cottonseed hulls. γ-Butyrolactone is a hygroscopic, colorless liquid that is obtained by the dehydrogenation of 1,4-butanediol and has a slight caramel sweet odor. Phenyl ethyl alcohol is a colorless liquid, with a faint odor of roses, that occurs naturally in many plants. For compound identification, we used solid-phase miroextraction to obtain extracts that were then analyzed by using gas chromatography. Analysis identified three compounds (Furfural, γ-Butyrolactone, and Phenyl ethyl alcohol) common between the three DDGS sources from Experiment 2.

To determine if a specific compound was responsible for negative impact on feed intake, we added twice the estimated concentration of each compound to corn-soybean meal diets. Compounds were prepared by thoroughly mixing 1/5 of the desired concentration into 1 lb of corn. This process was repeated five times. Next, we combined the 5 batches and mixed them to create a compound-corn mixture weighing 5 lb. The compound-corn mix was then mixed with 5 lb of corn to complete the 10-lb inclusion that was added to the complete diet (Table 4).

In this study we used a total of 140 pigs (PIC L327 x 1050) with an initial weight of 54.7 ± 1.8 lb. Pigs were blocked by sex for the 14-d trial. There were 7 pens with 20 pigs per pen.

Statistical Analysis. Data from all experiments were analyzed as a randomized design, with treatment within pen as the experimental unit. Analysis of variance was performed by using the MIXED procedure of SAS. Contrasts were used to determine the effect of

DDGS source and concentration in diets. Linear and quadratic polynomial contrasts were used in Experiment 2 to determine the effects of increasing DDGS concentration.

Results and Discussion

In Experiment 1, there was no significant difference between the control, plant-dried or hand-dried DDGS diets (Table 5) for ADFI from d 0 to 7, but feed intake was numerically less for both plant- and hand-dried DDGS sources. Pigs consumed less ($P<0.05$) of the diet with wet DDGS. From d 7 to 12 and overall, a difference in ADFI ($P<0.01$) was observed between the control diet and both drying types. Pigs preferred the control diet; both plant dried and hand dried had intermediate intake. Diets with wet DDGS had the least ($P<0.05$) feed intake. For the overall study, pigs showed a preference for corn-soybean meal diets over diets containing DDGS, regardless of DDGS, drying method. For the overall group, ADG was 1.68 ± 0.13 kg and F/G was 1.75 ± 0.17.

In Experiment 2, for d 0 to 7, d 7 to 14, and the entire trial, adding DDGS to diets decreased ($P<0.05$) ADFI compared with corn-soybean meal control diets (Table 6). Within diets containing 30% DDGS, pigs had greater ($P<0.05$) ADFI for Sources 1 and 6, compared with Source 7. But Source 1 had numerically less ADFI than did Source 6. For this study, the group ADG and F/G was 2.80 ± 0.04 kg and 2.08 ± 0.04, respectively.

In Experiment 3, for the entire trial, the addition of Furfural, γ-Butyrolactone, and Phenyl ethyl alcohol in corn-soybean meal diets had no effect ($P>0.92$) on feed intake (Table 7). The ADFI was numerically similar between all feeders, and illustrates that no differences in palatability were detected. For this study, the group ADG and G:F was 1.63 ± 0.06 kg and 2.17 ± 0.10 respectively.

New processing techniques and better quality control have lead to a better and more consistent nutrient profile of DDGS. With an improved nutrient profile and more attractive cost, DDGS are being used more frequently in swine diets. But studies evaluating the use of DDGS in swine diets have shown that, as amount of DDGS in the diet increased, there was a decrease in feed intake, independent of nutrient profile. Although many production systems and feed companies use DDGS, they typically limit DDGS inclusion to less then 15% of the diet. Higher concentrations are seldom used because of these reductions in feed intake. Practical diet formulation would allow higher concentrations of DDGS if it did not result in less feed intake. Some producers have shown no negative affects on feed intake with the inclusion of DDGS in swine diets. One commercial study showed no negative affect on intake when DDGS was added at 30% of the diet. But the inclusion of DDGS commonly reduces ADFI in field and research conditions. Feed intake of pigs is critical for pork production because it establishes nutrient intake rates and impacts efficiency of pork production. Feed intake is influenced by a variety of factors, such as stress, health status, genotype, energy density, feed processing, availability of water and flavors.

One of the primary reasons for limited use of DDGS in swine diets traditionally was the poor amino acid digestibilities due to overheating during the drying process. Researchers at the University of Kentucky evaluated nine different DDGS samples; four samples had either a smoky or a burnt odor. Authors did detect differences in feed intake among sources, with those having smoky or burnt odor having the least intake. Over-drying of DDGS may produce burnt or smoky flavors that are undesirable to swine. The variation in color and flavors may be the result of different drying temperatures and times, which can be different between plants. This may be one

explanation for the difference in intake seen between DDGS sources. New technology has provided improved ethanol production and drying techniques. Although none of the DDGS sources that we evaluated had smoky or burnt odors or dark color, differences in feed intake were still observed in our studies. Thus, we wanted to evaluate different drying methods and their effects on feed intake of diets with DDGS. Feed intake in Experiment 1 showed that, regardless of drying method, pigs fed diets with DDGS had reduced feed intakes.

Reports from commercial production have shown a variety of responses to feed intake when DDGS is added to diets. We wanted to further evaluate the effects of DDGS source on feed intake. We also wanted to measure the differences in feed intake between diets containing DDGS from corn and milo sources. Therefore, we obtained corn DDGS product from plants that reportedly had little negative effect of feed intake in swine. The corn plants selected were new-generation ethanol facilities in the upper Midwest (Sources 1 and 6). Milo DDGS (Source 7) was obtained from an ethanol production facility in Kansas. As data from Experiment 2 shows, differences in feed intake do exist between sources, even though few differences in color (of corn sources) and nutrient profile existed between the DDGS sources. Thus, whether a DDGS source is considered "good" for feed intake may not be represented in nutrient profile, color, or odor.

No difference in feed intake was detected between any of these compounds tested. Although many different compounds and their interactions contribute to flavor, it is difficult to identify one specific compound or trait in DDGS that decreases feed intake when included in swine diets.

Experiment 3 also indicates that there was no 'position preference' for any feeder, which contradicts work in rats that showed rats, when given a choice of same sources of fluid, showed a regular preference for one container. This problem may have been circumvented by rotation of the feeders twice daily. Providing multiple treatments within a pen allows researchers to evaluate more than one treatment at a given time, and provides indications of responses to treatments to determine if further evaluations are warranted.

These studies illustrate that pigs prefer corn-soybean diets over diets containing DDGS. The decreased palatability seems to increase with increasing amounts of dried distiller grains. Regardless of source, feed intake is decreased when DDGS is included in the diets. Although it seems that the ME content of DDGS is comparable to that of corn, palatability problems may affect pig performance, even when DDGS is included at low concentrations in the diet formulation.

Table 1. Composition of Dried Distillers Grains with Solubles Sources[a]

Item	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7
Dry matter, %	92.79	92.99	90.59	90.09	90.59	91.63	92.97
GE, kcal/kg	5,229	5,280	5,162	5,089	5,187	5,105	4,470
Crude protein, %	26.67	30.95	26.7	27.1	26.7	25.5	41.2
Crude fat, %	10.78	9.03	11.1	8.5	11.1	9.3	6.1
Crude fiber, %	5.61	7.62	9.3	9.2	9.3	11.3	9.5
Ash, %	6.16	3.91	3.6	4.4	3.6	4.3	2.6
Ca, %	0.06	0.04	0.08	0.04	0.05	0.07	0.04
P, %	0.73	0.50	0.64	0.67	0.65	0.79	0.27
K, %	0.90	0.51	0.84	0.88	0.89	1.04	0.34
Mg, %	0.31	0.16	0.28	0.29	0.30	0.37	0.13
Zn, ppm	54.1	39.1	47.6	70.8	39.1	61.7	17.4
Fe, ppm	58	46	63	67	65	75	29
Mn, ppm	9	7	8	10	10	14	9
Cu, ppm	5.9	5.1	5.1	4.9	4.6	5.5	2.9
S, %	0.37	0.37	0.30	0.53	0.74	0.51	0.11
Na, %	0.08	0.06	0.08	0.04	0.04	0.07	0.01
NDF, %	26.03	32.61	31.1	29.9	27.8	32.2	32.4
ADF, %	6.85	9.97	17.9	17.3	17.4	14.8	33.5
Amino acids,%							
Arginine	1.15	1.43	--	--	--	--	--
Histidine	0.75	0.98	--	--	--	--	--
Isoleucine	1.03	1.23	--	--	--	--	--
Leucine	3.28	3.97	--	--	--	--	--
Lysine	0.78	1.08	--	--	--	--	--
Met & Cys	1.08	1.42	--	--	--	--	--
Methionine	0.55	0.71	--	--	--	--	--
Phenylalanine	1.36	1.68	--	--	--	--	--
Threonine	1.07	1.25	--	--	--	--	--
Tryptophan	0.19	0.21	--	--	--	--	--
Tyrosine	1.12	1.28	--	--	--	--	--
Valine	1.40	1.66	--	--	--	--	--

[a]Analyzed values for corn DDGS (Sources 1 through 6) and milo DDGS (Source 7) from different sources.

Table 2. Composition of Diets in Experiment 1 (As-fed Basis)

		Dryer Type		
Item, %	Control	Plant Dry	Hand Dried	Wet
Corn	67.48	43.77	42.45	36.67
Soybean meal (46.5% CP)	30.02	24.31	23.58	20.37
DDGS	---	30.00	32.10	41.36
Monocalcium P (21% P)	0.75	---	---	---
Limestone	0.92	1.12	1.08	0.93
Salt	0.35	0.35	0.34	0.29
Vitamin premix[b]	0.15	0.15	0.15	0.13
Trace mineral premix[c]	0.15	0.15	0.15	0.13
Lysine HCl	0.15	0.15	0.15	0.13
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, %	28	34	34	34
Threonine, %	63	75	75	75
ME, kcal/lkg	3,331	3,435	3,435	3,435
Protein, %	19.7	23.3	23.3	23.3
Ca, %	0.61	0.58	0.58	0.58
P, %	0.55	0.52	0.52	0.52

Table 3. Composition of Diets in Experiment 2 (As-fed Basis)

		DDGS		
Item, %	Control	Source 1	Source 6	Source 7
Corn	67.51	37.91	37.87	37.63
Soybean meal (46.5% CP)	30.00	30.00	30.00	30.00
DDGS	---	30.00	30.00	30.00
Monocalcium P (21% P)	0.79	0.23	0.33	0.61
Limestone	0.92	1.21	1.15	1.01
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
Lysine HCl	0.10	---	---	0.10
DL-methionine	0.03	---	---	---
Total	100.00	100.00	100.00	100.00
Calculated analysis				
Lysine, %	1.2	1.24	1.24	1.24
Methionine, %	28	35	35	35
Threonine, %	63	80	80	71
ME, kcal/kg	3,330	3,420	3,419	3,086
Protein, %	19.7	25.5	25.5	29.5
Ca, %	0.62	0.62	0.62	0.62
P, %	0.56	0.56	0.56	0.56

Table 4. Composition of Diets in Experiment 3 (As-fed Basis)

		Compound		
Item, %	Control	Phenyl Ethyl Alcohol	Butyrolactone	Furfural
Corn	67.47	66.96	66.96	66.96
Soybean meal (46.5% CP)	30.02	30.00	30.00	30.00
Monocalcium P (21% P)	0.79	0.79	0.79	0.79
Limestone	0.92	0.92	0.92	0.92
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
Lysine HCl	0.15	0.15	0.15	0.15
DL-methionine	0.03	0.03	0.03	0.03
Compound + corn	---	0.50	0.50	0.50
Total				
Calculated Analysis				
Lysine, %	1.20	1.20	1.20	1.20
Methionine, %	29	29	29	29
Threonine, %	60	60	60	60
ME, kcal/kg	3,329	3,329	3,329	3,329
Protein, %	19.6	19.6	19.6	19.6
Ca, %	0.62	0.62	0.62	0.62
P, %	0.62	0.62	0.62	0.62

Table 5. Effects of Dried Distiller Grains Drying Method on Feed Intake, Experiment 1[a]

		Dryer Type			
ADFI, lb	Control	Plant Dry	Hand Dried	Wet	SE
d 0 to 7	0.75[b]	0.73[b]	0.69[b]	0.43[c]	0.04
d 7 to 12	0.93[b]	0.67[c]	0.67[c]	0.21[d]	0.03
d 0 to 12	0.84[b]	0.70[c]	0.68[c]	0.32[d]	0.03

[a]A total of 187 pigs (17 pigs per pen and 11 pens) initially 49.4 ± 1.8 lb were given the choice of one of four diets in the same pen; corn-soybean control or control with 30% DDGS replacing corn.
[b,c,d,e]Means within a row with different superscripts differ ($P<0.05$).

Table 6. Effects of DDGS Source on Feed Intake, Experiment 2[a]

		DDGS, 30%			
ADFI, lb	Corn	Source 1	Source 6	Source 7	SE
d 0 to 7	1.16[b]	0.88[c]	1.16[b]	0.57[d]	0.07
d 7 to 14	1.75[b]	0.83[c]	1.42[d]	0.37[e]	0.06
d 14 to 19	2.41[b]	0.73[c]	1.35[d]	0.23[e]	0.05
d 0 to 19	1.71[b]	0.82[c]	1.30[d]	0.41[e]	0.05

[a]A total of 112 pigs (16 pigs per pen and 7 pens) with initial wt of 69.9 ± 1.5 lb were given the choice of one of four diets in the same pen; corn-soybean control with 30% corn DDGS from one of two sources (Sources 1 and 6) or 30% milo DDGS (Source 7).
[b,c,d,e]Means within a row with different superscripts differ ($P<0.01$).

Table 7. Effects of Compounds Found in DDGS on Feed Intake, Experiment 3[a]

		Compound			
ADFI, lb	Control	Phenyl Ethyl Alcohol	Butyrolactone	Furfural	SE
d 0 to 7	0.84	0.84	0.87	0.84	0.03
d 7 to 14	0.94	0.92	0.92	0.93	0.03
d 0 to 14	0.89	0.88	0.90	0.89	0.01

[a]A total of 140 pigs (20 pigs per pen and 7 pens) with initial wt of 54.7 ± 1.8 lb were given the choice of one of four diets in the same pen; corn-soybean control or control plus Phenyl ethyl alcohol, Butyrolactone, or Furfural.

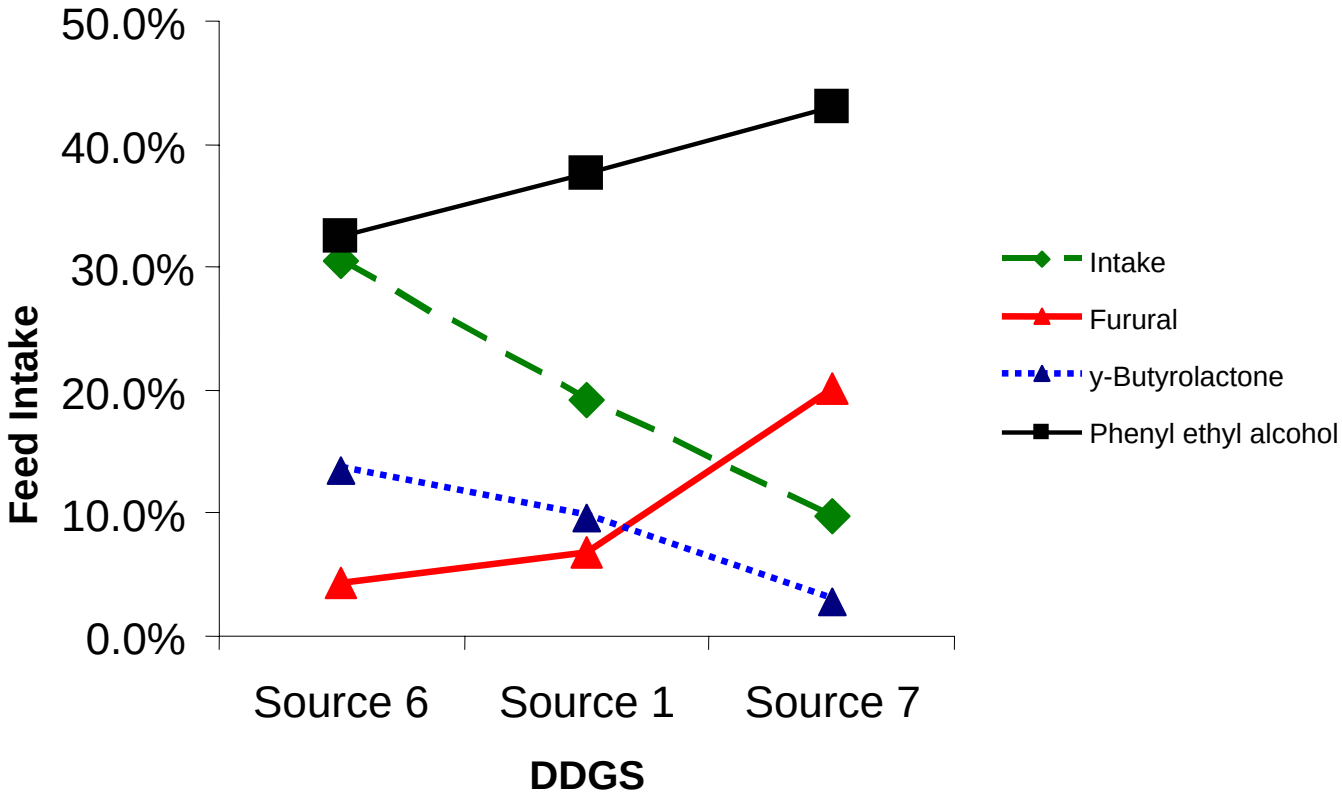


Figure 1. Graph of Feed Intake from Sources 1, 6, and 7 and Concentrations of Specific Compounds Found in each Source.

EFFECTS OF INCREASING DIETARY LYSINE ON GROWTH PERFORMANCE OF PIGS FED RACTOPAMINE HCl (PAYLEAN®)[1]

C. R. Neill, S. S. Dritz[2], M. D. Tokach, R. D. Goodband, J. L. Nelssen, J. M. DeRouchey, C. W. Hastad, and J. L. Usry[3]

Summary

A total of 919 gilts (PIC L337 × C22) were used in a 21-d trial conducted in a commercial research facility to determine growth and carcass effects of ractopamine HCl (Paylean®; 6.5 g/ton) and different levels of lysine. The diets were formulated to contain 0.75, 0.85, 0.95, 1.05, 1.15, and 1.25% true ileal digestible (TID) lysine to determine the lysine requirement for pigs fed ractopamine. These TID lysine levels correspond to 0.86, 0.97, 1.08, 1.19, 1.29, and 1.40% total lysine. From d 0 to 14, pigs fed 1.05% TID lysine had the greatest improvement in ADG and F/G. In the overall (d 0 to 21) data, however, pigs fed 1.15% TID lysine had the greatest improvement in ADG and F/G. Average daily gain increased (linear, $P<0.005$), whereas there were no differences in ADFI ($P>0.05$). Feed efficiency also improved (linear, $P<0.005$; quadratic $P<0.07$). Although the ADG and F/G responses were linear, there was very little improvement observed beyond 1.15% TID lysine. Percentage lean increased (linear, $P<0.03$) and FFLI tended to increase (linear, $P<0.07$) with increasing levels of TID lysine. The lean premium increased (linear, $P<0.05$) and backfat tended (linear, $P<0.08$) to improve, but other carcass criteria were not affected. Therefore, pigs fed ractopamine required between 1.05 and 1.15% TID lysine (1.19 to 1.29% total lysine) to maximize growth performance.

(Key Words: Carcass Parameters, Lysine, Paylean.)

Introduction

In December 1999, ractopamine HCl (Paylean®; Elanco, Indianapolis, IN) was approved for use in finishing diets for swine. Ractopamine has been shown to increase ADG, improve F/G, and increase pig weights. Feed intake tends to decrease when ractopamine is added to the diet, which makes it necessary to increase amino acids in the diet to ensure that the pig's requirements are met. With pigs growing faster, increasing lean accretion, and decreasing fat deposition, our objective was to determine the lysine requirement for pigs fed ractopamine the last 21 d before market.

Procedures

This experiment was conducted in a commercial finishing facility in southwestern Minnesota. There were 42 pens, with seven pens per treatment and 21 or 22 pigs per pen. A total of 919 gilts were allotted by weight,

[1]Paylean is a registered trademark of Elanco Animal Health, Indianapolis, IN.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.
[3]Anjinomoto Heartland Lysine LLC, Chicago, IL.

with an initial weight of 219 lb. Pens were totally slatted, with a self feeder and waterer. The facility was double curtain sided, with natural ventilation and a deep pit for manure storage. The six dietary treatments were based on the amount of true ileal digestible (TID) lysine in the diet (0.75, 0.85, 0.95, 1.05, 1.15, and 1.25%), and each treatment also contained 6.5 g/ton of Paylean (Table 1). These TID lysine levels correspond to 0.86, 0.97, 1.08, 1.19, 1.29, and 1.40% total lysine. All diets were based on corn-soybean meal, with 2% added fat and 1.5 lb/ton of crystalline lysine.

Pen weights and feed intake were determined on d 0, 7, 14, and 21 to calculate ADG, ADFI, and F/G. At the conclusion of the trial, pigs in each pen were identified with a unique tattoo to obtain carcass information. At the slaughtering facility (Swift Inc, Worthington, MN), carcass parameters were measured. Data were analyzed by using the PROC mixed procedure in SAS v. 8.1 as a randomized design.

Results and Discussion

From d 0 to 14, pigs fed 1.05% TID lysine had the greatest ADG and second-lowest F/G (2.59 and 2.25, respectively). Increasing TID lysine improved ADG (linear, $P<0.05$) and F/G (linear, $P<0.01$; quadratic $P<0.05$) from d 0 to 14. As the trial progressed (overall d 0 to 21), however, ADG and F/G had the greatest improvement when pigs were fed the 1.15% TID lysine treatment. Average daily gain increased (linear, $P<0.005$) and F/G improved (linear, $P<0.0004$; quadratic $P<0.07$) for the overall data, whereas there were no differences in ADFI ($P>0.75$). Although the ADG and F/G responses were linear, there was no improvement in growth observed for treatments above 1.15% TID lysine.

Percentage lean increased (linear, $P<0.03$) and FFLI tended to increase (linear, $P<0.07$ and quadratic, $P<0.09$). There was a linear trend ($P < 0.08$) for decreased backfat thickness with increasing TID lysine. The lean premium also improved (linear, $P<0.05$), but other carcass criteria were not affected by TID lysine level. In conclusion, pigs fed ractopamine in this commercial research barn required 1.05% to 1.15% TID lysine (1.19% to 1.29% total lysine) to optimize growth performance. These lysine concentrations are higher than previously observed in pigs fed ractopamine.

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

Item	TID[b] Lysine Content %					
Ingredient, %	0.75	0.85	0.95	1.05	1.15	1.25
Corn	78.84	71.84	67.85	63.85	59.85	55.86
Soybean meal (46.5% CP)	19.85	23.83	31.20	31.79	35.77	39.75
Choice white grease	2.00	2.00	2.00	2.00	2.00	2.00
Monocalcium P (21% P)	0.60	0.58	0.56	0.54	0.52	0.50
Limestone	1.10	1.10	1.10	1.10	1.10	1.10
Salt	0.40	0.40	0.40	0.40	0.40	0.40
L-Lysine HCl	0.075	0.075	0.075	0.075	0.075	0.075
DL-methionine	0.00	0.015	0.030	0.045	0.060	0.075
L-threonine	0.00	0.022	0.043	0.065	0.086	0.108
Vitamin premix	0.050	0.050	0.050	0.050	0.050	0.050
Trace mineral premix	0.050	0.050	0.050	0.050	0.050	0.050
Ractopamine HCl	0.036	0.036	0.036	0.036	0.036	0.036
Total	100	100	100	100	100	100
ME (Mcal/lb)	1.55	1.55	1.55	1.55	1.55	1.55
Total lysine, %	0.86	0.97	1.08	1.19	1.29	1.40
TID methionine, %	0.24	0.27	0.30	0.34	0.37	0.40
TID methionine+cystine, %	0.49	0.54	0.59	0.65	0.70	0.75
TID threonine, %	0.50	0.58	0.65	0.73	0.80	0.88
TID tryptophan, %	0.15	0.18	0.20	0.22	0.24	0.26
TID isoleucine, %	0.57	0.63	0.70	0.77	0.83	0.90
TID valine, %	0.65	0.72	0.79	0.85	0.92	0.98

[a]All diets were based on corn and soybean meal.

[b]True ileal digestible.

Table 2. Effects of Dietary Lysine Level on Performance of Pigs Fed Ractopamine[a]

	TID[b] Lysine, %							Probability, $P <$		
Item	0.75	0.85	0.95	1.05	1.15	1.25	SE	Trt	Linear	Quadratic
Initial weight, lb	219.0	219.0	219.1	219.1	219.0	219.0	3.09	1.00	0.99	0.98
d 0 to 14										
ADG, lb	2.36	2.36	2.49	2.59	2.55	2.50	0.08	0.25	0.05	0.22
ADFI, lb	5.85	5.71	5.78	5.83	5.69	5.78	0.11	0.89	0.69	0.72
F/G	2.49	2.44	2.32	2.25	2.23	2.34	0.07	0.06	0.01	0.05
d 0 to 21										
ADG, lb	2.12	2.16	2.20	2.28	2.34	2.27	0.06	0.07	0.005	0.34
ADFI, lb	5.83	5.71	5.75	5.80	5.82	5.77	0.09	0.93	0.88	0.75
F/G	2.76	2.64	2.62	2.54	2.49	2.56	0.05	0.005	0.0004	0.07
Final weight, lb	263.4	264.5	265.4	267.4	268.2	265.8	3.22	0.91	0.37	0.55
Carcass weight, lb	198.2	198.3	199.2	199.9	200.5	197.6	2.50	0.96	0.83	0.47
Yield %	76.13	75.75	76.25	75.66	75.66	75.77	0.004	0.78	0.39	0.88
Backfat, in	0.62	0.61	0.59	0.57	0.58	0.59	0.02	0.33	0.08	0.20
Loin depth, in	2.25	2.31	2.28	2.27	2.32	2.37	0.06	0.77	0.21	0.63
Lean %	56.16	56.39	56.88	56.87	57.00	56.91	0.30	0.28	0.03	0.27
FFLI	50.98	51.06	51.32	51.51	51.53	51.22	0.18	0.18	0.07	0.09
Carcass criteria, $[c]										
Sort loss/cwt	-1.86	-2.04	-1.94	-2.02	-2.05	-1.74	0.31	0.98	0.85	0.50
Value/cwt carcass[d]	72.96	73.11	73.38	73.26	73.24	73.57	0.38	0.91	0.31	0.94
Income/pig	144.05	144.49	145.41	146.43	146.51	146.17	1.77	0.88	0.24	0.66
Lean premium	4.25	4.57	4.74	4.70	4.71	4.73	0.17	0.29	0.05	0.17
Value live	54.71	54.42	55.15	55.26	54.80	55.72	0.52	0.58	0.16	0.79

[a]A total of 919 gilts (PIC L337 × C22; initially 219 lb) were used in a 21-d feeding trial. Pigs were fed ractopamine (6.5 g/ton), with 6 dietary treatments formulated to titrate the lysine requirement. A total of 42 pens were used, with 7 pens per treatment and 21 or 22 pigs per pen.

[b]True ileal digestible.

[c]Carcass base price was $70.58/cwt.

[d]Value/cwt for carcass was calculated as: carcass base price – sort + lean premium.

EFFECTS OF INTERMITTENT RACTOPAMINE HCl (PAYLEAN[1]) USE ON PIG GROWTH PERFORMANCE IN LATE FINISHING

C. R. Neill, R. D. Goodband, M. D. Tokach, J. L. Nelssen, S. S. Dritz[2], J. M. DeRouchey, C. N. Groesbeck, and K. R. Brown

Summary

A total of 324 pigs (initially 149 lb) were used in a 56-d feeding trial to examine growth performance of pigs as affected by different ractopamine HCl (Paylean) regimens. There were four experimental treatments: A) the control diet fed for 56 d; B) the Paylean diet (9 g/ton) fed for 21 d, then control for 35 d; C) Paylean fed for 21 d, then control for 14 d, and then Paylean for 21 d; and D) control diet 35 d and then Paylean 21 d. Treatment C (feeding Paylean for 21 d, withdrawing it for 14 d, and re-feeding for 21 d) had the same overall affect on ADG and F/G as feeding Paylean for the last 21 d only. Weight gain was greater ($P<0.008$) for the pigs in Treatments C and D, which fed Paylean for the last 21 d, compared with that of control pigs or those fed Paylean for the initial 21 d of the study only. Pigs fed Paylean and then had it withdrawn had decreased ($P>0.46$) ADG and F/G, compared with pigs not previously fed Paylean. These results suggest that withdrawing Paylean for 14 d and re-feeding will have the same overall growth effect as feeding Paylean once.

(Key Words: Finishing Pig, Paylean, Withdrawal.)

Introduction

Ractopamine (Paylean, Elanco, Indianapolis, IN) is a feed additive approved in the United States since December 1999 for use in swine diets. Paylean has been proven to increase ADG, improve F/G, and increase pig weights when fed immediately before market. In commercial production, however, when a finishing barn is closed out, there is still a small population of lightweight finishing pigs not yet ready for market. Many production systems move these lightweight pigs off site to be fed to market weight. Depending on the production system, pigs may be fed a diet with or without Paylean. Our goal was to determine the effects of Paylean withdrawal or intermittent Paylean feeding on growth performance and to develop recommendations on how to effectively manage Paylean use in lightweight pigs.

Procedures

This experiment was conducted at the Kansas State University Swine Research and Teaching Center. A total of 342 pigs (228 barrows, 96 gilts) with an initial weight of 148.9 lb were used in a 56-d feeding trial. The pigs (PIC L327 × L42 and PIC L210 × L42) were allotted by weight and put into pens of 11 or

[1]Paylean is a registered trademark of Elanco Animal Health, Indianapolis, IN.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.

12, with a total of 28 pens in a completely randomized block design with 7 pens per treatment. The pens had half solid and half slatted flooring with a deep pit and one curtain side. Each pen had one nipple waterer and a two-hole self feeder.

There were two diets used: a control diet (no Paylean) or the control diet containing 9 g/ton of Paylean. Diets were based on sorghum-soybean meal with no added fat, and included 3 lb/ton of synthetic lysine, formulated to contain 1.0% total lysine.

Table 1. Diet Composition %

Ingredient	Control
Sorghum	73.58
Soybean meal (46.5% CP)	23.85
Monocalcium P (21% P)	0.80
Limestone	0.93
Salt	0.35
Vitamin premix	0.15
Trace mineral premix	0.15
Antibiotic[a]	0.05
Lysine HCl	0.15
Ractopamine HCl[b]	-
Total	100.00
Lysine, %	1.00
ME, kcal/lb	1,483
Protein, %	17.90
Ca, %	0.60
P, %	0.55
Available P, %	0.25
Lysine:calorie ratio, g/mcal	3.06

[a]All diets contained 40 g/ton of tylosin.
[b]Ractopamine was added (9 g/ton) at the expense of sorghum to provide the Paylean diet.

Experimental treatments consisted of A) the control diet fed for 56 d; B) the Paylean diet (9 g/ton) fed for 21 d, and then the control diet fed for 35 d; C) Paylean fed for 21 d, the control diet fed for 14 d, and then the Paylean diet fed for 21 d; and D) the control diet fed for 35 d, and then the Paylean diet fed for 21 d. Pigs were weighed individually on d 21, 28, 35, 42, 49, and 56 to determine ADG, ADFI, and F/G. Statistical analysis was conducted according to SAS v. 8.1 by using the MIXED procedure in a randomized complete block design.

Results and Discussion

From d 0 to 21, Treatments B and C had increased ADG ($P<0.0003$; 2.11 lb for control and 2.34 lb for pigs fed Paylean) and improved F/G ($P < 0.0001$; 2.69 for control and 2.49 for pigs fed Paylean), compared with pigs fed diets without Paylean (Treatments A and D; Table 2). From d 21 to 35 (when no Paylean was fed) ADG was greater ($P<0.007$) for Treatments A and D, than for Treatments B and C (2.16 vs. 1.94 lb, respectively). There were no differences in F/G for this time period. For the last 21 d (d 35 to 56) of the trial, pigs fed Paylean (Treatment D) for the first time and pigs re-fed Paylean (Treatment C) had increased ADG ($P>0.0001$: 2.26 lb for pigs fed Paylean and 1.96 lb for the pigs not fed Paylean) and improved F/G ($P<0.0001$; 2.95 for pigs fed Paylean and 3.46 for pigs not fed Paylean), compared with pigs not fed Paylean (Treatments A and B).

For the overall 56-d trial, pigs fed Paylean from d 0 to 21 and withdrawn for 14 d and re-fed Paylean the last 21 d and pigs fed Paylean the last 21 d (Treatments C and D) had increased ADG ($P<0.003$) and improved F/G ($P<0.0001$) compared with pigs fed the control diet for 56 d and pigs fed Paylean from d 0 to 21 then fed the control diet from d 21 to 56 (Treatments A and B; 2.20 and 2.84 vs. 2.08 and 3.04, respectively). Pigs fed Paylean for 21 d then withdrawn for 14 d and then re-fed for 21 d (Treatment C) and those fed Paylean for the last 21 d (Treatment D) had heavier ($P<0.02$) weights at the end of the

trial, compared with pigs not fed Paylean or fed Paylean for the first 21 d only (Treatments A and B). Also, the weight gain was significantly more (P<0.008) for the pigs fed Paylean for 21 d then withdrawn for 14 d and then re-fed for 21 d and those fed Paylean for the last 21 d only (Treatments C and D), compared with pigs fed diets without Paylean or fed Paylean for the first 21 d only (Treatments A and B).

Pigs fed Paylean did not maintain the additional weight gain when later fed a diet without Paylean. These pigs had no significant additional weight at the end of the trial, compared with control pigs. Also, there was no additional weight gain from Treatment C, because their growth rate was less than that of the control pigs during the intermittent period. Some producers reportedly feed a withdrawal diet that does not contain Paylean after feeding Paylean, to ensure that feed bins contain Paylean-free feed for the next group of pigs. Our data indicates that some of the weight advantage to feeding Paylean will be rapidly lost with this practice, reducing the economic value of feeding Paylean.

It is interesting that the response to feeding Paylean intermittently during the re-feeding period seems to be similar to that of pigs fed Paylean for the first time. This indicates that withdrawing Paylean for a period of time and then re-feeding Paylean will have the same results as feeding pigs Paylean for the first time.

Table 2. Effects of Intermittent Ractopamine HCl (Paylean) Use on Pig Growth Performance in Late Finishing[a]

	Paylean Fed During These Days					
			0 to 21 and			Probability, $P <$
Item	None	0 to 21	35 to 56	35 to 56	SE	Treatment
Initial Weight, lb	148.9	149.0	148.8	149.0	0.110	0.13
d 0 to 21						
ADG, lb	2.10[b]	2.34[c]	2.34[c]	2.12[b]	0.057	0.001
ADFI, lb	5.73[bc]	5.87[c]	5.79[bc]	5.62[b]	0.097	0.11
F/G	2.72[b]	2.51[c]	2.47[c]	2.65[b]	0.049	0.001
d 21 to 35						
ADG, lb	2.12[c]	1.96[b]	1.92[b]	2.20[c]	0.080	0.007
ADFI, lb	6.55	6.28	6.33	6.57	0.177	0.26
F/G	3.09[bc]	3.22[bc]	3.32[b]	2.98[c]	0.125	0.07
d 35 to 56						
ADG, lb	1.98[b]	1.93[b]	2.25[c]	2.27[c]	0.047	0.001
ADFI, lb	6.80	6.72	6.63	6.68	0.171	0.76
F/G	3.45[b]	3.48[b]	2.94[c]	2.95[c]	0.082	0.001
d 0 to 56						
ADG, lb	2.06[b]	2.09[b]	2.20[c]	2.20[c]	0.041	0.003
ADFI, lb	6.33	6.29	6.23	6.25	0.116	0.85
F/G	3.07[b]	3.00[b]	2.83[c]	2.84[c]	0.033	0.001
Final weight, lb	265.4[c]	266.2[c]	272.0[b]	272.9[b]	2.573	0.02
Weigh gain, lb	116.5[c]	117.2[c]	123.2[b]	123.9[b]	2.471	0.008

[a]A total of 324 pigs (PIC L327 × L42 and PIC L210 × L42; 228 barrows and 96 gilts) initially 148.9 lb, with 28 pens and 11 or 12 pigs/pen.
[bc]Means in the same row without a common superscript differ ($P<0.05$).

EFFECTS OF CONTINUOUS OR INTERMITTENT RACTOPAMINE HCl (PAYLEAN[1]) USE ON PIG GROWTH PERFORMANCE IN LATE FINISHING

C. R. Neill, M. D. Tokach, S. S. Dritz[2], R. D. Goodband, J. L. Nelssen, J. M. DeRouchey, C. N. Groesbeck, and K. R. Brown

Summary

A total of 110 barrows (PIC L210 × L42) with an initial weight of 154.4 lb were used in a 56-d feeding trial to evaluate the effects of continuously feeding ractopamine HCl (Paylean; 9 g/ton), withdrawing Paylean, or intermittent Paylean feeding on finishing pig performance. There were five experimental treatments fed the last 56 d before marketing; A) control diet (no Paylean) fed for 56 d; B) Paylean diet (9 g/ton) fed for 56 d; C) Paylean fed for 21 d, control for 14 d, then Paylean for 21 d; D) control fed for 7 d, Paylean fed for 21 d, control fed for 7 d, then Paylean fed for 21 d; and E) control fed for 35 d, then Paylean fed for 21 d. Pigs fed Paylean for 21 d then withdrawn for 7 or 14 d and then re-fed for 21 d (Treatments C and D) had similar response to those fed Paylean for only the last 21 d before market (Treatment E). Pigs fed these three treatments had final weight numerically increased by 3 to 5 lb over that of pigs continuously fed Paylean for the entire 56 d. During the period when Paylean was withdrawn (7 or 14 d), pigs lost much of the benefit that had been gained from Paylean feeding. But pigs fed Paylean again later seem to respond similarly to pigs that had never had Paylean in the diet.

(Key Words: Finishing Pig, Paylean, Withdrawal.)

Introduction

When ractopamine (Paylean) is fed to finishing pigs, the growth rate increases, with improvement in F/G and carcass characteristics. Once Paylean was approved for swine diets in December of 1999, many swine producers began feeding it to their finishing pigs the last three weeks before slaughter. Feeding Paylean increases body weight, which can help decrease the number of lightweight pigs that have to be sold to the packer at a discount. When a finishing barn is closed out, there typically are still some lightweight pigs, which will be heavily discounted by the packer. In some production systems, the lightweight pigs are moved from the finishing barn to an off site barn to be fed out until they reach optimal market weight. Depending on the production system, these pigs will either remain continuously on a diet containing Paylean, or will be fed a diet without Paylean and then be re-fed Paylean as they approach the appropriate market weight. In a previous trial (see page 164), pigs fed Paylean at 9 g/ton for 21 d, had Paylean withdrawn for 14 d and were re-fed Paylean for 21 d had the same overall ADG and F/G as pigs that were fed Paylean for the

[1]Paylean is a registered trademark of Elanco Animal Health, Indianapolis, IN.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.

last 21 d only. We wanted to evaluate the growth response of pigs when Paylean was fed continuously for 56 d; fed for 21 d, withdrawn for either 7 or 14 d, and re-fed for 21 d; and fed for the last 21 d only.

Procedures

A total of 110 barrows (PIC L210 × L42) with an initial weight of 154.4 lb were used in a 56-d growth study with two pigs per pen and a total of 55 pens (5 × 5 ft). There were 11 replications (pens) on each of the five experimental treatments, in a randomized complete-block design. The pigs were blocked by weight and initial ADG from the previous two weeks before the pigs started on trial. The pigs were housed at Kansas State University Swine Research and Teaching Center in an environmentally controlled finishing barn with totally slatted flooring, a self feeder and one nipple waterer in each pen. Experimental treatments began 56 d before the pigs were marketed. The treatments were: A) control diet fed for 56 d; B) Paylean diet (9.0 g/ton) fed for 56 d; C) Paylean fed for 21 d, control fed for 14 d, then Paylean for 21 d; D) control fed for 7 d, Paylean for 21 d, control for 7 d, then Paylean for 21 d; and E) control for 35 d, then Paylean for 21 d. All experimental diets were based on sorghum-soybean meal and were formulated to contain 1.0% lysine with no added fat (Table 1). Pigs were weighed every 7 d to determine ADG, ADFI, and F/G. Statistical analysis was conducted as a repeated-measures experimental design by using the MIXED procedure of SAS.

Results and Discussion

From d 0 to 21, pigs fed Paylean had increased ($P<0.0001$) ADG and improved ($P<0.0007$) F/G, compared with pigs fed diets without Paylean (Table 2). When pigs were fed Paylean for 21 d then withdrawn for either 14 or 7 d and re-fed for 21 d (Treatments C and D), overall ADG and F/G was similar ($P>0.24$) to performance of pigs that were only fed Paylean for the last 21 days (Treatment E). Treatment E pigs had increased ADG, compared with the control pigs. Because the response to Paylean depended on the number of consecutive weeks that the pigs had received Paylean, there was a treatment × week interaction for ADG ($P<0.0001$). Pigs fed Paylean for all 56 d had improved ADG and F/G at the beginning of the trial and lost the positive response to Paylean by the end of the trial.

Table 1. Diet Composition (As-fed Basis)

Ingredient, %	Control
Sorghum	73.58
Soybean meal (46.5% CP)	23.85
Monocalcium P (21% P)	0.80
Limestone	0.93
Salt	0.35
Vitamin premix	0.15
Trace mineral premix	0.15
Antibiotic[a]	0.05
Lysine HCl	0.15
Ractopamine HCl[b]	-
Total	100.00
Lysine, %	1.00
ME, kcal/lb	1,483
Protein, %	17.9
Ca, %	0.60
P, %	0.55
Available P, %	0.25
Lysine:calorie ratio, g/mcal	3.06

[a]All diets contained 40 g/ton of tylosin.
[b]Ractopamine was added (9 g/ton) at the expense of sorghum to provide the Paylean diet.

In conclusion, withdrawing Paylean for 7 or 14 d, then re-feeding for 21 d, provided a similar response to feeding Paylean for only the last 21 d before market. These three treatments numerically increased final weight by 3 to 5 lb over continuously feeding Paylean for the entire 56 d. During the period when Paylean was withdrawn, pigs lost much of the benefit that had been gained from Paylean feeding. But pigs placed back on a diet containing Paylean seem to respond similarly to pigs that had never had Paylean in the diet. Therefore, it seems likely that weight gain will be greater and cost lower if lightweight pigs previously fed Paylean are moved to another facility and fed a diet without Paylean for 7 to 14 d, followed by another regimen of feeding Paylean, rather than continuously feeding the Paylean after the pigs have been moved.

Table 2. Effects of Continuous or Intermittent Ractopamine HCl (Paylean) Feeding on Pig Growth Performance in Late Finishing[a]

	Paylean Fed During These Days					
Item	None	0 to 56	0 to 21	7 to 28	35 to 56	SED
Initial weight, lb	153.4^{cy}	154.3^{bc}	153.8^{bcy}	155.1^{b}	155.3^{b}	0.765
d 0 to 21						
ADG, lb	2.34^{c}	2.75^{b}	2.81^{b}	2.78^{b}	2.39^{c}	0.095
ADFI, lb	7.26	7.50	7.60	7.35	7.51	0.242
F/G	3.11^{c}	2.74^{b}	2.70^{b}	2.65^{b}	3.14^{c}	0.139
d 0 to 28						
ADG, lb	2.31^{dy}	2.65^{bx}	2.57^{bcx}	2.73^{bx}	2.39^{cdy}	0.095
ADFI, lb	7.33	7.50	7.47	7.44	7.48	0.242
F/G	3.17^{cy}	2.84^{bx}	2.91^{bcx}	2.73^{bx}	3.13^{cy}	0.139
d 0 to 35						
ADG, lb	2.37^{cy}	2.60^{bx}	2.48^{bcxy}	2.60^{bx}	2.43^{bcy}	0.095
ADFI, lb	7.49	7.48	7.53	7.41	7.65	0.242
F/G	3.17^{dy}	2.89^{bcx}	3.03^{bcdxy}	2.86^{bx}	3.15^{cdy}	0.139
d 0 to 56						
ADG, lb	2.22^{cy}	2.29^{bcxy}	2.38^{bcx}	2.38^{bcx}	2.41^{bx}	0.095
ADFI, lb	7.56^{xy}	7.25^{y}	7.59^{xy}	7.29^{y}	7.72^{x}	0.242
F/G	3.42^{cy}	3.17^{bcx}	3.19^{bcx}	3.07^{bx}	3.20^{bcxy}	0.139
Final weight, lb	277.5^{cy}	284.7^{bcx}	286.9^{b}	288.5^{b}	290.4^{b}	4.084
Weight gain, lb	124.1^{c}	130.4^{bc}	133.1^{b}	133.4^{b}	135.1^{b}	4.174

[a]A total of 110 barrows (PIC L210 × L42) with eleven pens per treatment. Treatment × Week interaction for ADG (P<0.0001) and treatment response for F/G (P<0.0007) for the overall trial. Week (P<0.0001) also was significant for all criteria, but there was no treatment response for ADFI (P = 0.50).

[bcd]Means in the same row without common superscript differ (P<0.05).

[xy]Means in the same row without common superscript differ (P<0.10).

THE EFFECTS OF DIFFERENT NUTRIENT STRATEGIES ON REDUCING OSTEOCHONDROSIS DISSECANS LESIONS AND ENHANCING CARTILAGE PROPERTIES IN PIGS

N. Z. Frantz, J. L. Nelssen, G. Andrews[1], S. S. Dritz[2], M. D. Tokach, R. D. Goodband, and J. M. DeRouchey

Summary

A total of 80 gilts (PIC 327 × L1050; 86 lb initial BW) were used in an 84-d study to determine the effects of different nutrients on growth performance, carcass composition, the occurrence of osteochondrosis dissecans (OCD) lesions (a cartilage abnormality), and several cartilage criteria. Eight dietary treatments were formulated, consisting of control diet (standard corn-soy diet) or the control diet with fish oil (3.5%) replacing choice white grease; added proline and glycine (300% and 200% of lysine; added leucine, isoleucine, and valine (BCAA; 200%, 100%, and 100% of lysine, respectively); silicon (1000 ppm); copper and manganese (250 ppm and 100 ppm, respectively); added methionine and threonine (150% and 100% of lysine); and a combination of these strategies. The diets were formulated slightly in excess of the pig's requirement for lysine and to meet minimum true ileal digestibility (TID) ratios for the other essential amino acids. The diets were also formulated to be isocaloric by slightly adjusting the fat (choice white grease) content. Overall, d 0 to 84, pigs fed diets containing BCAA or silicon had greater ADG (P<0.05) than did those fed methionine/threonine or the combination diet; performance of pigs fed the remaining diets was intermediate. Pigs fed methionine/threonine had increased longissimus muscle area (P<0.05), compared with those fed the other dietary treatments, with longissimus muscle area of pigs fed fish oil intermediate. No other carcass responses were affected by dietary treatment (P>0.84). Pigs fed diets containing fish oil or silicon tended (P<0.07) to have an increased number of cartilage abnormalities and a higher score for severity of abnormalities (P<0.05), compared with those of pigs fed the other dietary treatments; scores of pigs fed proline/glycine or copper/manganese were intermediate. Pigs fed fish oil or silicon tended (P<0.07) to have a greater prevalence of potential lesions than did pigs fed the control diet, BCAA, methionine/threonine, or the combination diet; responses to the other dietary treatments were intermediate. Cartilage compression or shear force were unaffected by dietary treatment (P>0.31). In summary, feeding ingredients involved in cartilage and bone metabolism did not improve cartilage properties or reduce the incidence of OCD in gilts relative to the control diet in this study. Feeding diets containing fish oil or silicon caused an increase in the occurrence of potential lesions, the number of cartilage abnormalities, and the scores for severity of abnormalities.

(Key Words: Cartilage, Finishing Pig, OCD.)

[1]Department of Diagnostics/Pathobiology, College of Veterinary Medicine.
[2]Food Animal Health & Management Center, College of Veterinary Medicine.

Introduction

Osteochondrosis dissecans (OCD) remains a common problem among growing swine that occurs in approximately 85 to 90% of all pigs. Osteochondrosis dissecans is an irregularity in the underlying growth cartilage that has improperly calcified, leaving an area of cartilage protruding into the subchondral bone. It occurs primarily in the epiphyseal cartilage of the medial femoral condyle, humeral condyle, humeral head, and the growth plate of the distal ulna, costochondral junction, and the femur. It can cause reduced reproductive performance and increased culling rates in sows, and decrease performance and meat yield of finishing pigs. The direct cause of OCD is relatively unknown, but several studies have tried to determine how handling, moving, genetics, or nutrition may play a role in its development. It previously has been thought that rapid growth rate was a major cause of OCD in growing pigs. But current data indicate that OCD is caused by an abnormality in bone growth that causes cartilage canal vessels supplying blood to the end of growing long bones to improperly fill with bone matrix. The reduced blood supply provides an area of cartilage that is weakened and susceptible to trauma. When trauma occurs, this underlying weakness can allow damage to occur to the articular cartilage surface or can prevent the cartilage around it from properly maturing and growing at the appropriate rate. This damage to the articular cartilage surface results in pain and stiffness associated with the common lameness and decreased mobility seen in many pigs.

Different nutrients recently have been evaluated for their ability to prevent arthritis and osteoarthritis in humans and animal models of the disease. Several amino acids and minerals play important roles in cartilage metabolism, and may present ways to intervene and prevent cartilage degradation or disease progression. The non-essential amino acids proline and glycine make up the building blocks of the collagen type II molecules that provide the framework of cartilage. In addition, the essential amino acid lysine plays a similar role in the makeup of collagen, whereas methionine provides a source of sulfur to form disulfide bonds and connect other molecules within the collagen molecule, and may influence cartilage metabolism. The branched-chain amino acids are involved in enzyme production and protein synthesis, as well as several of the protein components of the extracellular matrix, such as biglycan, fibromodulin, and decorin, leucine-rich proteins. Copper is involved in an enzyme, lysyl oxidase, that catalyzes the conversion of hydroxylysine residues in forming cross-links that stabilize the extracellular matrix. Manganese is involved in bone metabolism and cartilage formation through manganese-dependent glycosyltransferases, which are involved in the synthesis of proteoglycans. Manganese also has antioxidant activity on its own and in the mitochondria as manganese superoxide dismutase. Silicon is a mineral found in the earth's crust that has not been found to be essential in pigs; it may be involved in bone metabolism, however, and is found in collagen to link chondroitin sulfate molecules together. Fish oil contains high concentrations of the omega-3 fatty acids DHA and EPA that can potentially block the production of inflammatory intermediates by blocking the production of cytokines. This strategy may reduce the effects of specific cytokines that activate matrix metalloproteinases (MMP), which control the rate of extracellular matrix degradation and reduce expression of the type II collagen gene.

Therefore, the objective of this experiment was to screen dietary ingredients involved in cartilage and synovial fluid synthesis for their influence on growth performance, carcass characteristics, OCD lesions, and several cartilage criteria in growing-finishing pigs.

Procedures

General. Procedures used in these experiments were approved by the Kansas State University Animal Care and Use Committee. A total of 80 gilts (PIC line 327 × L1050; 86 lb initial BW) were blocked by weight in an 84-d growth assay. They were randomly allotted to one of eight dietary treatments. Dietary treatments consisted of control (standard corn-soy diet) or the control diet with fish oil (3.5%) replacing choice white grease; added proline and glycine (300% and 200% of lysine, respectively); added leucine, isoleucine, and valine (BCAA; 200%, 100%, and 100% of lysine, respectively); silicon (1000 ppm); copper and manganese (250 ppm and 100 ppm, respectively); added methionine and threonine (150% and 100% of lysine, respectively); and a combination of these strategies. Experimental diets were fed in meal form for 84 d. Pigs were phase-fed over the 84 d period, consisting of three 28-d phases. The values used in diet formulation and TID digestibilities were based on those published in the NRC (1998). Diet samples were analyzed for amino acid content.

The experiment was conducted at the Kansas State University Swine Research and Teaching Center. Each pen contained one pig, for a total of ten replicates (pigs) per treatment. The barn contains 80 totally slatted concrete pens (5 × 4 ft), providing approximately 20 sq ft per pig. Each pen was equipped with a one-hole dry self-feeder (Farmweld, Tuetopolis, IL) and nipple waterer to allow *ad libitum* access to feed and water.

Growth Performance and Carcass Composition. Pigs and feeders were weighed on d 0, 14, 28, 42, 56, 70, and 84 to determine ADG, ADFI, and F/G. At the start of the trial, all gilts were ultrasound scanned to determine initial backfat depth and longissimus muscle area. At the end of the trial, pigs were weighed before transport to the Kansas State University Meats Laboratory, where the left hind leg was collected for determination of OCD lesions as well as carcass data. Before transport, each pig was marked with a distinctive tattoo to allow the carcass data to be recorded for each pig. Carcass data were collected on each pig to evaluate 10th rib backfat depth, longissimus area, percentage lean, fat-free lean gain, and hot carcass weight. Fat depth was measured with a ruler at the 10th rib, 0.4 inch off the midline of the hot carcass, whereas longissimus area was traced on translucent paper and calculated using a grid. Percentage lean was calculated by using a standard equation, and fat-free lean index was calculated according to NPPC (1994) procedures.

Collection of Cartilage Data and OCD Lesions Scores. The left hind leg with an intact hip joint was collected and removed to visually determine the number of cartilage abnormalities and the occurrence of OCD lesions by visual examination. The joints were stored in 10% formalin until evaluation. Samples were evaluated for the number of abnormalities, given a severity of abnormality score (0 to 3), and given a "Yes" or "No" score for the presence or absence of a potential OCD lesion. In addition, a cartilage sample was cut from the proximal head of the femur. Cartilage samples were weighed, measured for thickness and length with a caliper, and then tested with an Instron machine to measure the ability to absorb compression or to resist shearing. Cartilage samples were placed between two flat surfaces of the Instron to perform the texture-profile analysis and were compressed half of the thickness to measure the ability of the cartilage to resist compression force. A second measure was conducted in which the cartilage was cut with a Warner-Bratzler shear blade to determine the ability of the cartilage to withstand shearing force. Compression values and shear values were adjusted to values per gram of cartilage weight to equalize for differences in the actual cartilage weight.

Statistical Analysis. Data were analyzed as a randomized complete-block design by using the PROC MIXED procedure of SAS, with pig as the experimental unit. The response criteria of growth performance, carcass composition, cartilage compression and shearing, number of abnormalities, severity of abnormalities score, and presence of potential OCD lesions were tested. Comparison of the presence of potential OCD lesions was done by chi-square analysis.

Results and Discussion

From d 0 to 28, pigs fed BCAA, silicon, or copper/manganese had greater ADG ($P<0.01$) than did pigs fed diets containing fish oil, proline/glycine, methionine/threonine, or the combination diet; ADG of pigs in the other treatments was intermediate. Pigs fed copper/manganese also tended to have improved F/G ($P<0.08$), compared with F/G of pigs fed fish oil, proline/glycine, methionine/threonine, or the combination diet; results of the other treatments were intermediate.

From d 0 to 56, pigs fed BCAA had greater ADG ($P<0.01$) than did pigs fed fish oil, proline/glycine, methionine/threonine, or the combination diet; ADG of pigs in the other treatments was intermediate. In addition, pigs fed copper/manganese had improved F/G ($P<0.05$), compared with F/G of pigs fed diets containing proline/glycine, methionine/threonine, or the control diet; results of the other dietary treatments were intermediate. Dietary copper addition has been shown to improve feed efficiency in the early growing-finishing phase in previous trials.

Overall, d 0 to 84, pigs fed diets containing BCAA or silicon had greater ADG ($P<0.05$) than did pigs fed methionine/threonine or the combination diet; ADG of pigs fed the remaining diets was intermediate.

Pigs fed methionine/threonine had increased longissimus muscle area ($P<0.05$), compared with that of pigs in the other dietary treatments; results of pigs fed fish oil were intermediate, but no other carcass differences were observed ($P>0.84$). This response is similar to previous trials in which excess methionine has increased longissimus muscle area.

Pigs fed diets containing fish oil or silicon tended ($P<0.07$) to have an increased number of cartilage abnormalities and had a higher score for severity of abnormalities ($P<0.05$), compared with scores of pigs in the other dietary treatments; scores of pigs fed proline/glycine or copper/manganese were intermediate. Pigs fed fish oil or silicon tended ($P<0.07$) to have a greater incidence of potential lesions than did pigs fed the control diet, BCAA, methionine/threonine, or the combination diet; incidence of potential lesions in pigs fed the other dietary treatments was intermediate. Cartilage compression and shear values were unaffected by dietary treatment ($P>0.31$).

In summary, feeding pigs added copper/manganese during the early growing-finishing phase resulted in improved F/G, compared with feeding the control diet. Feeding pigs diets containing fish oil or silicon tended to increase the occurrence of lesions and cartilage abnormalities compared with feeding the control diet. This may be due to a reduction in cartilage turnover by decreasing the production of matrix metalloproteinases with fish oil or by altering cartilage metabolism and bone metabolism with silicon. Feeding ingredients involved in cartilage and bone metabolism did not improve cartilage properties or reduce the incidence of OCD, relative to the control diet, in this study. Feeding diets containing fish oil or silicon caused an increase in the occurrence of lesions, the number of abnormalities, and the scores for severity of abnormalities.

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

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	62.65	62.81	58.47	61.47	61.21	62.46	61.62	54.59
Soybean meal (46.5% CP)	30.45	30.42	30.80	30.54	30.56	30.45	30.53	31.13
Choice white grease	3.50	-	3.00	3.30	4.00	3.50	3.00	-
Menhaden fish oil	-	3.30	-	-	-	-	-	3.00
Monocalcium P (21 % P)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Limestone	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.06	0.06	0.07	0.07	0.07	0.06	1.05	1.08
L-threonine	0.06	0.06	0.06	0.06	0.06	0.06	0.45	0.45
L-valine	-	-	-	0.27	-	-	-	0.29
L-isoleucine	-	-	-	0.35	-	-	-	0.35
L-leucine	-	-	-	0.60	-	-	-	0.65
L-proline	-	-	2.55	-	-	-	-	2.55
L-glycine	-	-	1.70	-	-	-	-	1.70
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 1. (continued)

Calculated analysis								
Total lysine, %	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
True ileal digestible amino acids								
Lysine, %	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Isoleucine:lysine ratio, %	69	69	69	100	69	69	69	100
Leucine:lysine ratio, %	145	145	145	200	145	145	145	200
Methionine:lysine ratio, %	32	32	32	32	32	32	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	65	65	65	65	65	65	100	100
Tryptophan:lysine ratio, %	20	20	20	20	20	20	20	20
Valine:lysine ratio, %	76	76	76	100	76	76	76	100
ME, kcal/lb	1568	1568	1568	1568	1568	1568	1568	1568
CP, %	19.5	19.5	19.3	19.4	19.4	19.5	19.4	19.1
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Available P	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.36	13.62	1.46	1.40	1.30	1.36	1.44	13.71
N-6 fatty acids, %[b]	33.38	28.32	34.52	33.88	31.71	33.36	34.96	28.96
N-6:N-3 ratio	24.55	2.08	23.59	24.28	24.37	24.52	24.25	2.11
Unsaturated:saturated ratio	58.4	49.3	59.4	58.6	59.6	58.5	58.1	52.0
Lysine:calorie ratio, g/mcal	3.47	3.47	3.47	3.47	3.47	3.47	3.47	3.47

[a]Diets fed in meal form from d 0 to 28.
[b]Expressed as a percentage of the total fat in the diet.

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

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	68.61	68.72	65.04	67.61	67.12	68.37	67.66	61.59
Soybean meal (46.5% CP)	24.96	24.95	25.26	25.04	25.09	24.98	25.04	25.56
Choice white grease	3.35	-	3.00	3.30	3.95	3.45	3.00	-
Menhaden fish oil	-	3.25	-	-	-	-	-	3.05
Monocalcium P (21 % P)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Limestone	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.13	0.13	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	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.03	0.03	0.04	0.03	0.04	0.03	0.90	0.90
L-threonine	0.05	0.05	0.06	0.05	0.06	0.05	0.40	0.40
L-valine	-	-	-	0.22	-	-	-	0.23
L-isoleucine	-	-	-	0.30	-	-	-	0.30
L-leucine	-	-	-	0.45	-	-	-	0.50
L-proline	-	-	2.15	-	-	-	-	2.15
L-glycine	-	-	1.45	-	-	-	-	1.45
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 2. (continued)

Calculated analysis								
Total lysine, %	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
True ileal digestible amino acids								
Lysine, %	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Isoleucine:lysine ratio, %	69	69	69	100	69	69	69	100
Leucine:lysine ratio, %	154	154	154	200	154	154	154	200
Methionine:lysine ratio, %	31	31	31	31	31	31	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	66	66	66	66	66	66	100	100
Tryptophan:lysine ratio, %	19	19	19	19	19	19	19	19
Valine:lysine ratio, %	78	78	78	100	78	78	78	100
ME, kcal/lb	1573	1573	1573	1573	1573	1573	1573	1573
CP, %	17.4	17.4	17.3	17.4	17.4	17.4	17.4	17.1
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Available P	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.23	13.26	1.29	1.24	1.17	1.22	1.28	13.42
N-6 fatty acids, %[b]	34.28	28.92	35.04	34.32	32.24	33.92	35.39	29.43
N-6:N-3 ratio	27.96	2.18	27.13	27.74	27.67	27.91	27.73	2.19
Unsaturated:saturated ratio	53.4	45.0	53.9	53.6	55.0	53.7	53.0	46.9
Lysine:calorie ratio, g/mcal	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03

[a]Diets fed in meal form from d 28 to 56.
[b]Expressed as a percentage of the total fat in the diet.

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

Item	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Copper/ Manganese	Methionine/ Threonine	All Ingredients
Ingredient								
Corn	74.03	74.19	71.07	73.30	72.60	73.79	73.23	68.01
Soybean meal (46.5% CP)	19.52	19.51	19.78	19.59	19.65	19.55	19.59	20.04
Choice white grease	3.30	-	3.00	3.25	3.85	3.40	3.00	-
Menhaden fish oil	-	3.15	-	-	-	-	-	3.10
Monocalcium P (21 % P)	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Limestone	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase	0.13	0.13	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	0.13	0.13
L-lysine HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-methionine	-	-	0.01	-	-	-	0.75	0.75
L-threonine	0.05	0.05	0.05	0.05	0.05	0.05	0.33	0.33
L-valine	-	-	-	0.17	-	-	-	0.18
L-isoleucine	-	-	-	0.25	-	-	-	0.25
L-leucine	-	-	-	0.30	-	-	-	0.35
L-proline	-	-	1.75	-	-	-	-	1.78
L-glycine	-	-	1.25	-	-	-	-	1.25
Silicon	-	-	-	-	0.75	-	-	0.75
Manganese sulfate	-	-	-	-	-	0.02	-	0.02
Copper sulfate	-	-	-	-	-	0.10	-	0.10

Table 3. (continued)

Calculated analysis								
Total lysine, %	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
True ileal digestible amino acids								
Lysine, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Isoleucine:lysine ratio, %	70	70	70	100	70	70	70	100
Leucine:lysine ratio, %	164	164	164	200	164	164	164	200
Methionine:lysine ratio, %	29	29	29	29	29	29	123	124
Met & Cys:lysine ratio, %	60	60	60	60	60	60	151	151
Threonine:lysine ratio, %	67	67	67	67	67	67	100	100
Tryptophan:lysine ratio, %	19	19	19	19	19	19	19	19
Valine:lysine ratio, %	80	80	80	100	80	80	80	100
ME, kcal/lb	1571	1571	1571	1571	1571	1571	1571	1571
CP, %	15.4	15.4	15.2	15.3	15.3	15.4	15.3	15.1
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
P, %	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Available P	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Copper ppm	11	11	11	11	11	250	11	250
Manganese ppm	26.4	26.4	26.4	26.4	26.4	100	26.4	100
Silicon ppm	-	-	-	-	1000	-	-	1000
N-3 fatty acids, %[b]	1.08	12.83	1.13	1.09	1.04	1.07	1.12	13.18
N-6 fatty acids, %[b]	34.79	29.66	35.48	34.87	32.86	34.42	35.76	29.77
N-6:N-3 ratio	32.17	2.31	31.47	31.99	31.73	32.09	32.02	2.26
Unsaturated:saturated ratio	49.0	41.1	49.1	49.1	50.8	49.3	48.4	42.5
Lysine:calorie ratio, g/mcal	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60

[a]Diets fed in meal form from d 56 to 84.
[b]Expressed as a percentage of the total fat in the diet.

Table 4. Effect of Different Nutrients on Growth Performance[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/Thr	All Ingredients	SE	Probability, P <
d 0 to 28										
ADG, lb	2.41^{def}	2.29^{cde}	2.25^{cde}	2.48^{f}	2.42^{ef}	2.50^{f}	2.23^{cd}	2.21^{c}	0.089	0.01
ADFI, lb	5.00	4.96	4.87	5.05	4.93	4.94	4.87	4.72	0.215	0.89
F/G	2.08^{cd}	2.17^{c}	2.17^{c}	2.04^{cd}	2.04^{cd}	1.98^{d}	2.18^{c}	2.15^{c}	0.077	0.08
d 0 to 56										
ADG, lb	2.38^{de}	2.27^{cd}	2.26^{cd}	2.47^{e}	2.39^{de}	2.39^{de}	2.17^{c}	2.19^{c}	0.080	0.01
ADFI, lb	5.57^{d}	5.23^{cd}	5.32^{cd}	5.64^{d}	5.54^{d}	5.21^{c}	5.16^{c}	5.02^{c}	0.212	0.05
F/G	2.34^{c}	2.31^{cd}	2.36^{c}	2.28^{cd}	2.32^{cd}	2.19^{d}	2.38^{c}	2.30^{cd}	0.075	0.31
d 0 to 84										
ADG, lb	2.40^{cd}	2.34^{cd}	2.37^{cd}	2.48^{d}	2.44^{cd}	2.48^{d}	2.28^{c}	2.28^{c}	0.104	0.21
ADFI, lb	6.13^{d}	5.85^{cd}	5.97^{cd}	6.17^{d}	6.16^{d}	6.04^{cd}	5.82^{cd}	5.68^{c}	0.248	0.26
F/G	2.56	2.50	2.52	2.50	2.53	2.45	2.55	2.50	0.087	0.91

[a]Treatments with different superscripts [c,d,e,f] differ by P<0.05.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb and an average final weight of 290 lb.

Table 5. Effect of Different Nutrients on Carcass Composition[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/ Thr	All Ingredients	SE	Probability, P <
Initial backfat, in	0.22	0.21	0.20	0.22	0.20	0.20	0.21	0.20	0.016	0.83
Initial LEA, in	1.42	1.52	1.53	1.41	1.47	1.46	1.43	1.45	0.092	0.86
Hot carcass weight[c]	209.6	205.8	205.0	209.1	212.7	206.8	201.3	197.1		
Final backfat, in	0.631	0.615	0.593	0.563	0.555	0.609	0.632	0.627	0.061	0.84
Final LEA, in	7.55[de]	7.92[ef]	7.46[de]	7.52[de]	7.49[de]	7.58[de]	8.27[f]	7.28[d]	0.327	0.05
Lean, %	55.47	55.69	55.29	55.74	55.75	55.48	56.14	54.51	1.088	0.90
Fat-free lean gain/ day, lb	0.936	0.953	0.949	0.955	0.957	0.948	0.960	0.926	0.025	0.88

[a]Treatments with different superscripts [d,e, f] differ by $P < 0.05$.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb and an average final weight of 290 lb.

[c]Hot carcass weight was used as a covariate in analysis.

Table 6. Effect of Different Nutrients on Cartilage Parameters[ab]

	Control	Fish Oil	Proline/ Glycine	BCAA	Silicon	Cu/Mn	Meth/Thr	All Ingredients	SE	Probability, P <
Cartilage weight, g[c]	1.07	1.26	1.08	1.22	1.24	1.10	1.16	1.26	0.138	0.72
Cartilage thickness, cm[d]	0.38	0.37	0.36	0.38	0.36	0.33	0.36	0.39	0.042	0.90
Cartilage length, cm[e]	3.19	3.37	3.22	3.25	3.28	3.21	3.30	3.32	0.109	0.71
Compression force, n/g[f]	-326.4	-520.5	-548.6	-500.5	-389.3	-390.0	-512.5	-424.8	148.5	0.87
Shear force, n/g[g]	-418.9	-370.4	-375.9	-488.3	-427.5	-476.4	-401.3	-411.0	59.8	0.31
No. of pigs with lesions[h]	5[k]	9[l]	8[kl]	5[k]	9[l]	5[k]	6[kl]	5[k]		0.14
No.of abnormalities/pig[i]	1.4[k]	2.4[l]	2.0[kl]	1.3[k]	2.4[l]	1.7[kl]	1.3[k]	1.4[k]	0.54	0.17
Average severity score[j]	1.7[mn]	2.5[n]	1.9[mn]	1.5[m]	2.5[n]	1.8[mn]	1.4[m]	1.4[m]	0.48	0.10

[a]Treatments with different superscripts [k,l] differ by P < 0.07 and [m,n] differ by P < 0.05.

[b]Each value is the mean of 9 or 10 replications with pigs initially 86 lb.

[c]Weight of the cartilage sample taken from the chondyle on the end of the femur.

[d]The thickness of the cartilage sample measured as it would sit perpendicular to the joint surface.

[e]The length of the cartilage sample measured as it would sit parallel with the joint surface.

[f]Amount of energy, in newtons per gram of cartilage, to compress the cartilage half its thickness.

[g]Amount of energy, in newtons per gram of cartilage, to shear the cartilage into two pieces.

[h]Number of pigs per treatment with potential lesions, by visual inspection of cartilage surface.

[i]The average number of abnormalities per pig, by visual inspection of the cartilage surface.

[j]Assigned a score of 0 to 3, where 0 = no damage and 3 = abnormalities that are severe.

A COMPARISON OF BYGHOLM FEED SIEVE TO STANDARD PARTICLE-SIZE ANALYSIS TECHNIQUES

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

Summary

Three experiments were conducted to evaluate the Bygholm Feed Sieve particle size tester. The Bygholm Feed Sieve is an 11 inch × 2.25 inch × 4.25 inch plastic box divided into four compartments by three different screen sizes (3,000-, 2,000-, and 1,000-micron mesh). In Experiment 1, particle size was determined for 20 ground corn samples with a Ro-Tap 13-sieve stack (53- to 3,350-micron Tyler mesh screens).The particle sizes ranged from 543 to 1,741 microns. Samples were analyzed for particle size with the standard Bygholm Feed Sieve, operated according to the manufacturer's directions. In Experiment 2, two rubber balls were placed on the 2,000 micron screen and one ball was placed on the 1,000 micron screen in the Bygholm Feed Sieve to aid in moving particles through the screens. Samples were then analyzed for particle size, according to the manufacturer's directions. In Experiment 3, 24 additional samples with particle sizes ranging from 604 to 1,305 microns were analyzed to determine the accuracy of the regression equation created by Experiment 1. After initial analysis indicated that the equation didn't accurately predict particle size of samples with a large particle size, an additional 11 samples with particle sizes ranging from 1,054 to 1,741 microns were analyzed. After this analysis, all samples from Experiments 1 and 3 were used to develop a new set of regression equations to calculate the particle size of samples over a wider micron range. The Bygholm Feed Sieve more accurately predicted the particle size of samples when rubber balls were not present within the system (R^2 = 0.88 versus 0.82). The regression equation created by Experiment 1 predicted 90% of the samples to be within 100 microns of the actual particle size when the samples were less than 1,000 microns. When samples are coarser than 1,000 microns, however, the regression equation created by Experiment 3 should be used; it predicts 85% of the samples to be within 100 microns of the actual particle size when the samples were larger than 1,000 microns and 98% of all samples to be within 150 microns of the actual particle size.

(Key Words: Particle Size, Ground Corn, Bygholm Feed Sieve.)

Introduction

Particle-size analysis of ground corn is recommended for swine diets. The importance of obtaining a particle size between 650 and 750 microns is stressed because of the improvement of feed efficiency due to the decrease of particle size. Particle-size analysis can also aid in determining when feed mill equipment maintenance is warranted. Sending samples to a commercial lab is recommended,

[1]Food Animal Health & Management Center, College of Veterinary Medicine.

but there is a need for equipment that can be used to measure particle size on the farm and in feed mills. The standard 13-screen method requires a large initial investment; both the 3- and 13-screen sieve systems require time and purchase of several components. As a result, the Danish Institute of Agricultural Sciences created the Bygholm Feed Sieve to simplify this process. The Bygholm Feed Sieve is an 11 inch × 2.25 inch × 4.25 inch plastic box divided into four compartments by three different screen sizes. The first compartment is 3.5 inches long and is divided from the second compartment by a 3,000-micron screen. The second, third, and fourth compartments are all 2.5 inches long. A 2,000-micron screen divides the second and third compartments, and a 1,000-micron screen divides the third and fourth compartments. Little research has been performed regarding the accuracy and usefulness of this feed sieve for ground corn. Therefore, our objective was to determine the accuracy of the Bygholm Feed Sieve to predict the particle size of ground corn. The second objective was to determine whether the accuracy of the sieve is improved by adding rubber balls, similar to those used in normal particle-size analysis, to the two lower screens.

Procedures

Experiment 1. To determine the accuracy of the standard Bygholm Feed Sieve, ground corn with a known particle size and standard deviation was placed in the largest compartment of the Bygholm Feed Sieve. According to the directions provided with the sieve, the lid was slid in, and the sieve was shaken vigorously for approximately 4.5 minutes, until no more sample could be shaken through each screen. The sieve was then placed lid-up and shaken to smooth the sample over the bottom of each compartment. The height of sample in each compartment was measured with the aid of incremental measurements on the side of the sieve and recorded. The heights were used to calculate a percentage of each sample contained by each compartment. The percentages on each screen were used to develop a regression equation (Regression Equation 1) to determine whether the actual particle size could be accurately predicted. This was replicated with 20 ground corn samples with particle sizes ranging from 568 to 1,741 microns.

Experiment 2. To evaluate the effects of adding rubber balls to the sieve, two 5/8-inch rubber sieve-cleaning balls (Codema, Inc.) were added to the second compartment and one ball was added to the third compartment to aid in the movement of the sample through the 2,000 micron and 1,000 micron screens. Further procedures were carried out according to the manufacturer's directions as in Experiment 1. This was replicated with 30 ground corn samples. The percentages on each screen were used to determine whether the accuracy could be improved, compared with the accuracy of equations developed without the balls in Experiment 1.

Experiment 3. To evaluate the accuracy of the regression equation created in Experiment 1, an additional 24 samples with particle sizes ranging between 604 and 1,305 microns were analyzed by the Bygholm Feed Sieve. Because the regression equation from Experiment 1 was generated from a data set in which most of the samples were between the recommended ranges of 600 to 800 microns, we analyzed an additional 11 samples with particle sizes ranging from 1,054 to 1,741 microns. The same procedures outlined in Experiment 1 were used in this experiment. A new regression equation (Regression Equation 2) was created that combined all data from Experiments 1 and 3 to create an equation that could be used to predict the particle size of ground corn samples over a wider range of particle sizes.

Results and Discussion

Experiment 1. The original procedures developed for the Bygholm Feed Sieve are accurate, provided that all the sample gets shaken through the screens. Due to the small surface area of the screens and the limited amount of shaking space, this can prove to be difficult. It takes approximately 4.5 to 5 minutes to adequately shake all the sample through the sieves. If this is done properly, the sieve performs well in accurately predicting the particle size of ground corn. The equation developed from Experiment 1 (Table 1) demonstrates that particle size for 19 of the 20 samples was predicted within 100 microns of the actual particle size (Figure 1). The equation indicated that 88% of the variation in particle size was predicted by the percentage of particles on each screen in the sieve (R^2 of 0.88). Because almost all of the samples in this experiment were less than 1,000 microns, Regression Equation 1 should not be extended to samples with larger particle sizes.

Experiment 2. The deviation of the predicted particle size in microns was determined and graphed with an R^2 of 0.82 (Figure 2). The results of testing the Bygholm Feed Sieve with balls present to aid in particle movement through the sieve were compared with the ability of the sieve to accurately predict the particle size of ground corn without balls present. The procedure carried out without balls generally had less deviation of micron size from the known particle-size value (Figure 3). Thus, balls should not be used with the Bygholm Feed Sieve. We believe that the balls may displace some of the grain when measuring the percentage of sample on each screen and, thus, increase the error in the measurement.

Experiment 3. The first part of Experiment 3 was to expand the dataset to determine the accuracy of the equation established in Experiment 1 for a wider range of particle sizes. Because the equation did not seem appropriate for samples with particle size larger than 1,000 microns, a second regression equation was developed. Regression Equation 1 was graphed for closeness of fit to the actual particle size, with the R^2 determined to be 0.87. The deviation in particle size, shown in Figure 4 demonstrates that the accuracy of Equation 1 becomes poorer, with greater deviation, as particle size increases. Regression Equation 2 was graphed for closeness of fit to the actual particle size, with the R^2 determined to be 0.92. The difference in accuracy between the two equations is particularly evident when comparing the prediction of particle size for coarser samples with particle size bigger than 1,000 microns (Figure 5).

Conclusions. The most accurate way to measure particle size is with a Ro-Tap 13-sieve stack, but the time commitment and initial cost of equipment makes that an impractical method of particle-size analysis on the farm or in most feed mills. The 3-screen sieve test previously recommended by Kansas State University works well for on-farm particle-size analysis, but the initial cost and requirement for an accurate scale for this system has led us to explore other options. The Bygholm Feed Sieve provides an alternative for producers, allowing them to predict the particle-size of their feed through a less expensive and less complicated mechanism. Adding rubber balls to more accurately mimic the standard Kansas State University 3-screen test increased the deviation of predicted micron size from the known particle size, because the surface area of the screens and compartments do not allow for these balls to easily be accounted for.

Regression Equation 1 was successful in predicting the particle size of ground corn smaller than 1,000 microns. For samples larger than 1,000 microns, however, or samples whose approximate particle size is unknown,

Regression Equation 2 is recommended. Although either the Bygholm Feed Sieve or 3-screen test can be used to estimate particle size in feed mills, producers should send monthly samples from their mill to a lab for a complete 13-screen sieve analysis. The results can be used to confirm the results of the on-farm analysis and will provide a standard deviation of the ground grain, which can not be determined from the Bygholm Feed Sieve or 3-screen test.

Table 1. Regression Equations Developed in Experiments 1 and 3

Equation	Regression Parameters[a]	R^2
1	= -25.1 + 22.363w +16.777x + 3.894y + 6.968z	0.88
2	= -1172 + 69.709w + 25.297x + 0y + 25.518z - 1.173w^2 + 0.1151 x^2 + 0.2139y^2 - 0.055 z^2	0.92

[a]Where w, x, y, and z are the percentages of the sample above the 3,000-, 2,000-, 1,000-micron screens, and pan, respectively.

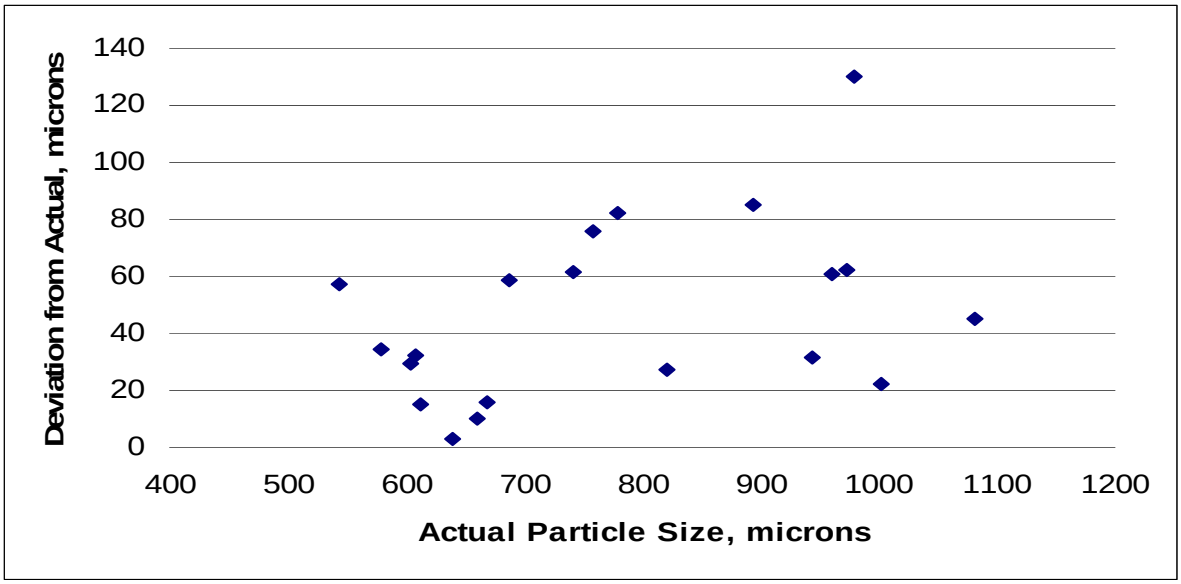


Figure 1. Deviation of Particle Size Predicted with the Bygholm Feed Sieve from Actual Particle Size (Experiment 1).

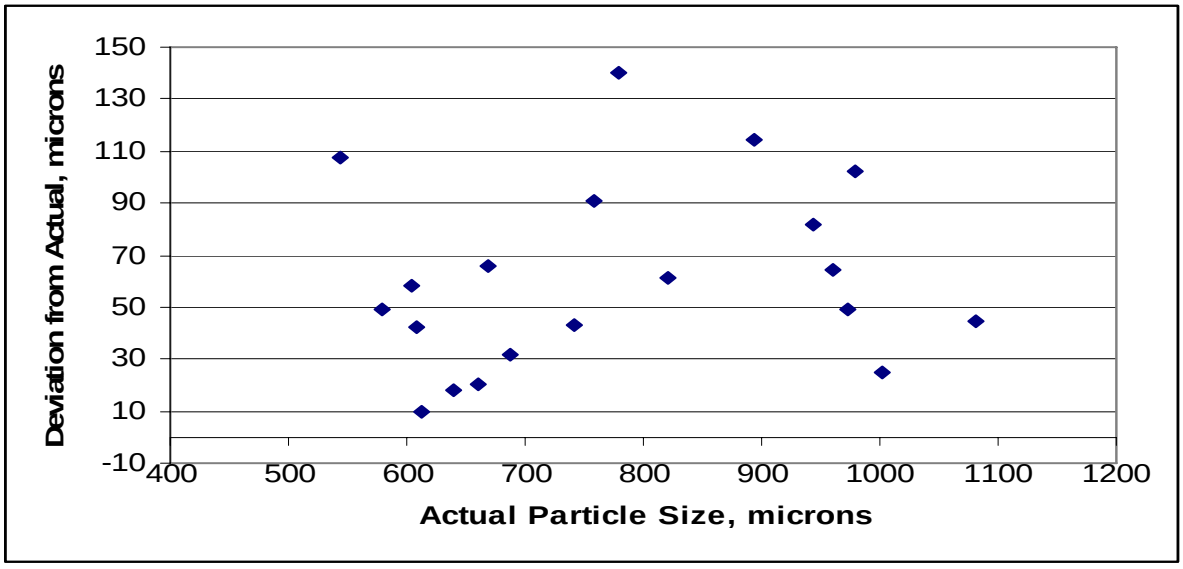


Figure 2. Deviation of Predicted Particle Size Predicted with the Bygholm Feed Sieve from Actual Particle Size, with Balls Present.

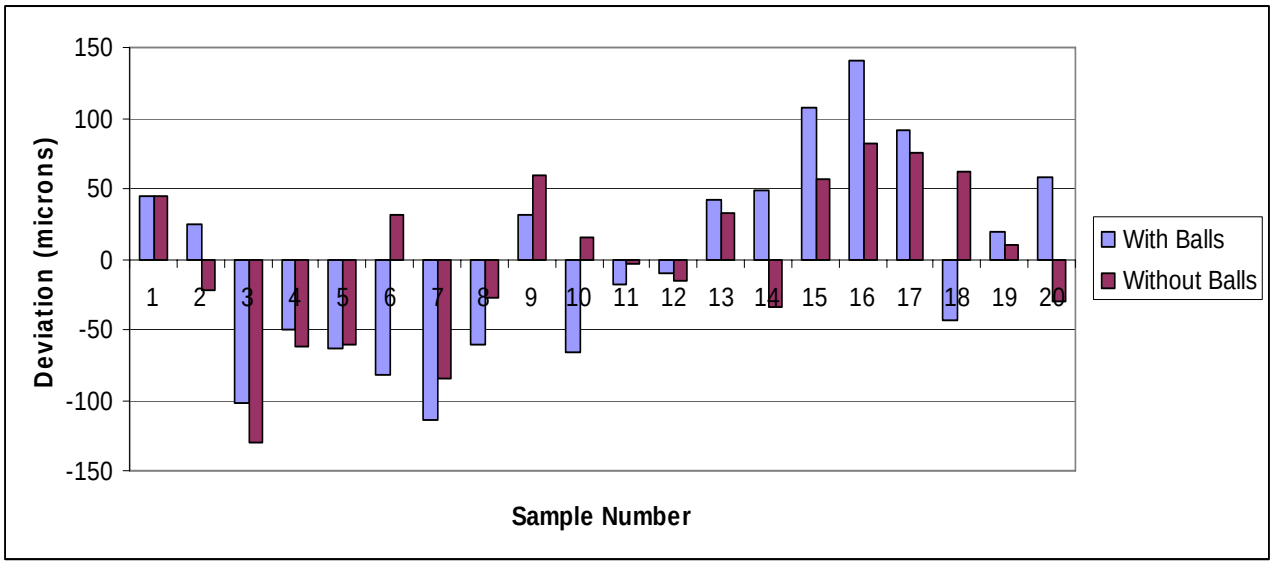


Figure 3. Deviation of Actual Particle Size from Particle Size Predicted with the Bygholm Feed Sieve, With or Without Balls on the Lower Two Sieves during Testing.

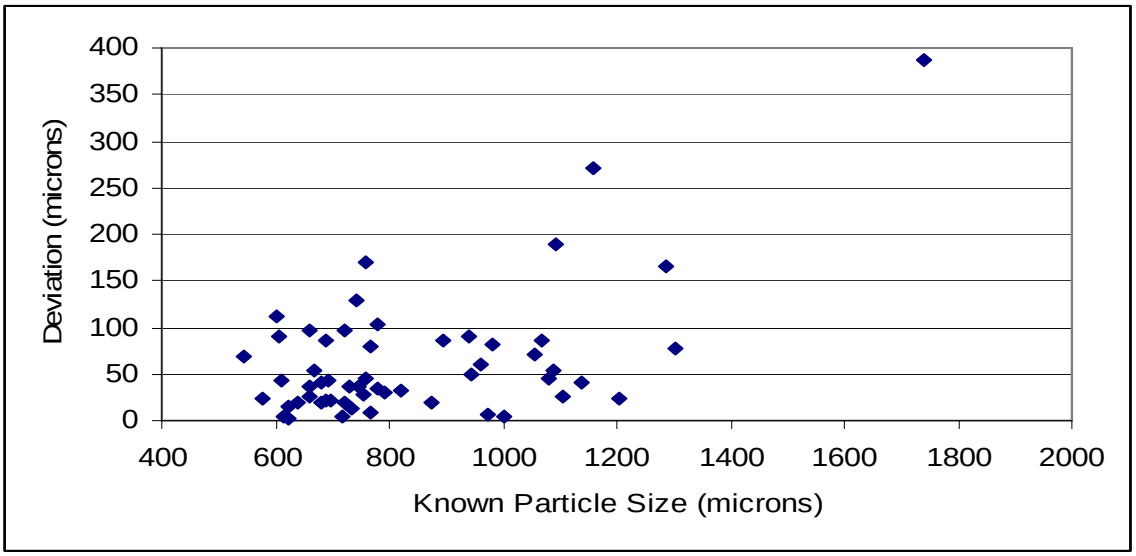


Figure 4. Deviation of Actual Particle Size from Particle Size Predicted with Equation 1 in Experiment 3.

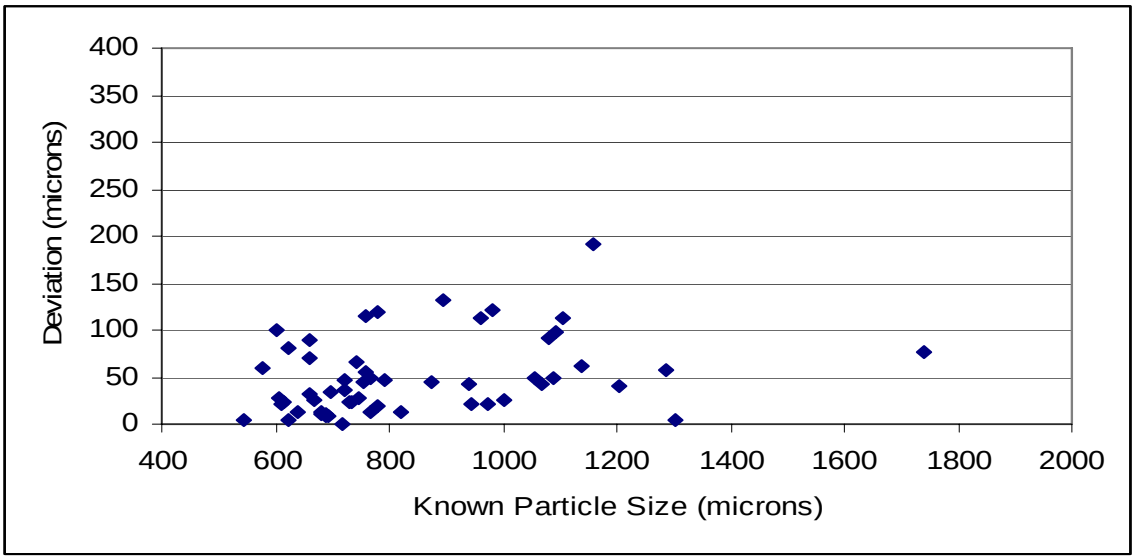


Figure 5. Deviation of Actual Particle Size from Particle Size Predicted with Equation 2 in Experiment 3.

EFFECTS OF ORAL ADMINISTRATION OR FEEDING OF SODIUM CITRATE OR ACETATE TO PIGS ON POST-MORTEM GLYCOLYSIS, PH DECLINE, AND PORK QUALITY ATTRIBUTES

J. W. Stephens, M. E. Dikeman, J. A. Unruh, M. D. Haub[1], and M. D. Tokach

Summary

Previous studies have shown that citrate has the potential to inhibit phosphofructokinase (PFK), a key enzyme in post-mortem glycolysis. The objective of our study was to determine the effects of oral administration and feeding of citrate or acetate to pigs on post-mortem glycolysis, pH, and pork quality attributes. In Experiment 1, citrate, acetate, or water was orally administered to 30 pigs 45 min before stunning (electric plus captive bolt). In Experiment 2, citrate or acetate was fed to 30 gilts in 454 g of feed 60 min before stunning. Ante-mortem treatment had no effect ($P > 0.05$) on muscle pH or post-mortem concentrations of glycolytic metabolites: glucose-6 phosphate, fructose-6 phosphate, fructose-1,6 bisphosphate, glyceraldehyde-3 phosphate, dihydroxyacetone phosphate, or lactate. Minor, but inconsistent, differences in quality attributes were found in *longissimus* chops and inside and outside *semimembranosus* quality attributes among treatments ($P>0.05$). The reason for the lack of PFK inhibition is not known. Glycolytic-metabolite data indicate that PFK was a main regulatory enzyme in post-mortem muscle.

(Key Words: Pork, pH, Glycolysis, Citrate, Acetate.)

Introduction

Attributes that define pork quality include color, firmness, wetness, and marbling, and are of great economic importance as they affect consumer appeal, eating satisfaction, and repeat purchases. Muscle color, firmness, and wetness are dependent on the reactions of glycolysis and pH decline during the onset of rigor. Anaerobic glycolysis, which occurs in post-mortem muscle, produces lactate and hydrogen ions. These hydrogen ions accumulate in muscle and reduce pH. If this reaction occurs at an accelerated rate before adequate chilling, the combination of low pH and high temperature has the potential to denature muscle proteins, resulting in pale color, softness, and diminished water-holding capacity.

Glycolysis is regulated by the enzyme phosphofructokinase (PFK) in post-mortem muscle. This enzyme catalyzes the reaction that transfers a phosphate group from adenosine triphosphate (ATP) to fructose-6 phosphate (F6P) to form fructose-1,6 bisphosphate and adenosine diphosphate (ADP). Although ATP is a substrate for this reaction and is the source of the transferred phosphate, it also serves as an inhibitor of the enzyme. In live animals, excess ATP indicates excess energy; therefore, ATP inhibits PFK, slowing glycolysis and, ultimately, ATP production. High

[1]Department of Human Nutrition.

concentrations of ADP in the cell indicate a lack of energy, thus ADP activates PFK.

Citrate is produced in the body from Acetyl CoA and oxaloacetate as the first step of the aerobic citric-acid cycle, and has been shown to inhibit PFK in mammalian muscle. Citrate inhibits PFK by binding directly to PFK and decreasing the enzyme's affinity for its substrate, F6P, and its activator, ADP. Citrate also increases the enzyme's affinity for ATP at the substrate site and, more importantly, the inhibitory site.

In preliminary investigations in pigs, we found that oral administration of 0.75 g/kg of body weight of citrate or acetate before handling increased post-handling blood pH. Because oral administration of citrate or acetate is not feasible in an industry setting, administering the glycolytic inhibitors through feed was also studied. The objective of our study was to determine the effects of oral administration or feeding of sodium citrate or acetate to pigs on post-mortem glycolysis, pH decline, and pork quality attributes.

Procedures

Preliminary Study. Two groups of 12 finishing pigs were blocked by weight and assigned to citrate, acetate, or control treatments. The pigs were fasted for no less than 20 h. Pigs were restrained with a snout snare and given their ante-mortem treatments by placing a tube through the mouth and down the esophagus. Pigs assigned to citrate and acetate treatments were given 0.75 g/kg BW of sodium citrate or sodium acetate in a 3-to-1 solution of distilled water, followed by 60 ml of water to flush out the tube. Control pigs were given 180 ml of distilled water. Pigs were allowed to rest for 30 min, and then were moved at a trotting pace up and down the aisles in their barn (approximately 100 m).

Forty-five minutes after treatment was ingested, the pigs were snared and bled via the anterior *vena cava* into a heprinized vacuum tube. Tubes were stored on ice for no more than 4 h before being analyzed for pH and lactate. Citrate and acetate treatments tended ($P = 0.18$) to increase blood pH. One h and 15 min after treatment, the pigs were bled again, and the blood parameters were similar among treatments.

Experiment 1. Two replications (one of 15 gilts and one of 5 gilts and 10 barrows) were fed a standard finishing diet containing 20 ppm ractopamine 14 d before harvest. Pigs were assigned by weight to ten groups of three. Pigs in each weight group were assigned to citrate (CIT), acetate (ACE), or control (CON) ante-mortem treatments. Before harvest, the pigs were fasted for no less than 20 h and transported to the Kansas State University Meat Laboratory. Final weights ranged from 230 to 330 lb. At 45 min before harvest, pigs were restrained with a snout snare and were given their ante-mortem treatments as described for the preliminary study. Pigs were harvested in random order within their weight group.

Experiment 2. Two replications of 15 gilts were fed a standard finishing diet containing 20 ppm ractopamine for 13 d before slaughter. Slaughter weights ranged from 235 to 305 lb. Gilts were fasted for no less than 20 h, were weighed, and were grouped by weight into 10 groups of three. Treatments (ACE, CIT, and CON) were assigned randomly to the gilts in each weight group. One h before harvest, gilts were fed 1 lb of feed containing 0.34 g / lb BW of either CIT or ACE. To counteract the salty taste of the treatments, 0.34 g of the artificial sweetener Sucram (Prince Agri. Products, Quincy, IL) was added to the feed. Control pigs received feed with Sucram, but no glycolytic inhibitor. The gilts harvested on the first replication were reluctant to eat the saltier

flavor of treated feed in the unfamiliar surroundings of the meat laboratory. Therefore, salt was gradually added to the feed for pigs in the second replication for 8 d before slaughter to familiarize them with the salty taste.

Harvest. Immediately before harvest, pigs were restrained with a snout snare and bled via the anterior *vena cava* into a heprinized vacuum tube. Tubes were stored on ice for no more than 4 h before being analyzed for pH and lactate. Bicarbonate concentrations also were calculated.

After blood samples were taken, pigs were gently moved to the abattoir, stunned by using an electric stunning wand and, in Experiment 1, stunned again by using a captive bolt stunner. Pigs then proceeded through the slaughter process according to normal procedures. After final inspection and wash, carcasses were tagged for identification, and a temperature logger was placed in the inside ham (*semimembranosus*; SM). The probe was positioned so that tip of the probe was 15 cm from the inside ham surface. The data loggers were launched to read temperature every 2.4 min for 24 h.

At 20 min post-mortem, a sample (approximately 1-inch-thick chop) was removed from the anterior portion of *longissimus* (LM) muscle (immediately posterior to the *scapula*), cut into cubes, and frozen in liquid nitrogen. This sample was used to analyze pre-rigor pH, glucose-6 phosphate (G6P), fructose-6 phosphate (F6P), fructose-1,6 bisphosphate (F16BP), combination of glyceraldehyde-3 phosphate and dihydroxyacetone phosphate (GAPDAP), and lactate.

At 24 h (Experiment 1) and 48 h (Experiment 2) post-mortem, carcasses were fabricated into loins and hams. Two chops (1 inch thick) were removed from the LM; one chop was allowed to bloom for no less than 30 min before visual evaluation. Three trained panelists evaluated each chop for color, firmness, and wetness. Color was evaluated on a six-point scale according to official color standards from the National Pork Producers Council (1 = lightest and 6 = darkest). Firmness and wetness were evaluated separately on three-point scales (1 = softest and wettest and 3 = firmest and driest). Chops were evaluated in random order within weight groups. The SM was excised from the ham, and a slice (1 inch thick) was removed. Ham slices were allowed to bloom for no less than 30 min before visual panel evaluation. Inside and outside sections of the SM were evaluated separately for color, firmness, and wetness as discussed for LM chops. After visual evaluation, L*, a*, and b* were measured on the chops and ham slices. The second loin chop was vacuum packaged until used for pH and expressible-moisture analysis. The inside and outside sections of the SM slices were separated with a knife, vacuum packaged, and held at 1^{o}C for pH and expressible-moisture analysis.

Statistical Analysis. Blood parameters were analyzed in a randomized, complete-block design, with weight group as the block. Temperature measurements were analyzed in a randomized block design with repeated measures, and weight group as the block. Pre-rigor pH and glycolytic metabolites were analyzed in a split-plot design, with ante-mortem treatment as the whole plot and time post-mortem as the sub-plot. The whole plot was blocked by weight group. Instrumental color, expressible moisture, and ultimate pH were analyzed in a randomized, complete-block design, with weight group as the block. Ante-mortem treatment and time post-mortem were the fixed effects, and weight group was the random effect. Visual color, firmness, and wetness were analyzed in a randomized, complete-block design, with panelist as the block. Ante-mortem treatment was again the fixed effect; panelist was the random effect. Data

were analyzed by using PROC MIXED and means were separated by using the PDIFF test when $P<0.05$.

Results and Discussion

Blood Parameters. Mean values for blood pH, bicarbonate, and lactate concentration 45 min after oral administration (Experiment 1) and 60 min after feeding (Experiment 2) of CIT, ACE, or control are presented in Table 1. In Experiment 1, CIT or ACE ingestion did not affect blood pH level or bicarbonate concentration. Lactate concentration in pigs orally administered CIT was greater ($P<0.05$) than in controls, but ACE-treated pigs did not differ ($P>0.05$) from control or CIT-treated pigs. In Experiment 2, blood pH level and bicarbonate and lactate concentrations were not affected ($P>0.05$) by treatment with ACE or CIT. In our preliminary studies of finishing pigs, we showed an alkalizing effect on blood by both CIT and ACE. CIT is an alkaline substance that has been shown to increase blood pH, bicarbonate, and lactate in humans. In Experiment 1, CIT-treated pigs had elevated lactate concentrations, but pH was not affected by CIT or ACE in either experiment. High lactate concentrations were likely a function of the animals maintaining homeostasis and regulating blood pH.

Post-mortem Glycolysis and Pre-rigor pH. Ante-mortem treatment did not effect concentrations of glycolytic metabolites during post-mortem glycolysis (Tables 2 and 3) or pre-rigor pH ($P>0.05$; Table 4) in either Experiment 1 or 2. Time post-mortem did affect ($P<0.05$) muscle pH. In Experiment 1, pH was highest ($P<0.05$) at 20 min post-mortem. Mean values of pH were higher ($P<0.05$) at 45 min than at the remaining times post-mortem, but pH values at 3-, 6-, 12-, and 24-h post-mortem did not differ ($P>0.05$). In Experiment 2, pH decreased ($P<0.05$) with increasing post-mortem time until 12 h. This pH decline was expected and is consistent with lactate accumulation. In both experiments, temperature declined over time, and did not differ ($P > 0.05$) among treatments (data not shown).

Ingestion of CIT before exercise has been shown to increase blood pH and improve performance in human athletes, but it has also been shown to have no effect on exercise performance. Exercise physiologists theorize that athletes with more alkaline conditions in their blood during exercise have enhanced performance over athletes with neutral and acidotic blood conditions. The extreme effects of slaughter of our pigs on the body were assumed to be similar to exhaustive anaerobic exercise, but neither CIT nor ACE administration affected post-mortem muscle pH conditions in our study.

Citrate has another effect on metabolism; it is an inhibitor of PFK in muscle, thus having the potential to inhibit glycolysis and post-mortem pH decline. In rats, it has been shown that acetate ingestion increases post-mortem muscle CIT concentrations and decreases PFK activity. It is thought that ACE is converted to CIT in the body by CIT synthase, and CIT inhibits glycolysis. Nonetheless, neither CIT nor ACE altered concentrations of glycolytic metabolite, compared with CON, whether administered orally or added to feed.

PFK Over Time. Changes in glycolytic-metabolite concentrations over time were similar for Experiments 1 and 2. Concentrations of G6P and F6P increased ($P<0.05$) as post-mortem time increased (Tables 2 and 3); F16BP and GAPDAP decreased ($P<0.05$) with post-mortem time. Lactate is the final product of glycolysis, and it accumulated ($P<0.05$) with time. It is thought that PFK plays a major role in regulation of post-mortem glycolysis, because metabolites that serve as substrates for PFK accumulate in post-mortem muscle, and PFK products (with

the exception of lactate) decrease with time. Our glycolytic-metabolite results are in agreement with the previous research: G6P and F6P increased with post-mortem time, whereas F16BP and GAPDAP decreased. Lactate is the final product of post-mortem glycolytic reactions, and it increased with the onset of rigor in our study.

Pork Quality Traits. Mean values for visual evaluations, instrumental color, expressible moisture, and ultimate pH for the LM and inside and outside SM are presented in Tables 5 and 6. In Experiment 1, visual color scores for the LM chops from ACE-treated pigs were higher ($P<0.05$) than those from CON; scores from chops from pigs treated with CIT were intermediate. Loin chops from ACE-treated pigs also had higher ($P<0.05$) scores for wetness (drier) than those from CIT and CON carcasses. Firmness scores did not differ ($P>0.05$) among treatments. Chops from CIT-treated pigs were lighter (larger L* values; $P<0.05$) and more yellow (larger b* values, $P<0.05$) than chops from control or ACE-treated pigs were. Chops from CIT-treated pigs also had larger ($P<0.05$) a* values (more red) than chops from control pigs had. Chops from ACE-treated pigs had intermediate values. Expressible-moisture and ultimate pH values did not differ ($P>0.05$) among treatments for LM chops.

In Experiment 2, chops from CIT-fed pigs were softer and wetter ($P<0.05$) than those from CON and ACE-fed pigs (Table 6). Chops from CIT-fed pigs also had lower ($P<0.05$) ultimate pH values than those from CON and ACE-fed pigs. Nevertheless, visual color, instrumental color, and expressible-moisture data in the LM were not affected ($P>0.05$) by ante-mortem feeding of CIT or ACE.

Pork quality attributes of the inside and outside SM were unaffected ($P>0.05$) by ante-mortem oral administration or feeding of ACE or CIT. This large ham muscle was studied because of the large variation in temperature. The outer section of the SM is closer to the surface of the carcass, due to the splitting process, and chills faster than the inner portion. The inner portion, located deep within the ham, is slower to chill, and is more susceptible to protein denaturation than the outer section because of the higher temperatures. Citrate and ACE were expected to slow post-mortem glycolysis in the inside SM, allowing it to chill before the pH dropped to a protein-denaturing level.

Neither CIT nor ACE were effective at inhibiting post-mortem glycolysis or slowing pH decline and, consequently, did not positively affect pork quality traits.

The reason that CIT and ACE did not effectively inhibit pH decline and did not improve meat quality is not known. Perhaps our preliminary data were misinterpreted in that the peak of blood pH should not have been the goal. If CIT was having maximal effects on the blood, it may not have had time to cross the membrane into the muscle. Furthermore, exsanguinations may have removed most of the CIT and ACE in the blood before it had time to have an effect in muscle. Perhaps more time should have been allowed between CIT or ACE administration and stunning.

The stressful handling during bleeding and the strange surroundings associated with the pre-slaughter protocol might have had an effect on the pigs' metabolism. Moreover, pigs in Experiment 1 were stunned with a captive-bolt stunner, which induced excessive kicking during exsanguination. This extra activity may have caused the pigs to metabolize glucose stores while the blood system was still intact to remove excess lactate and to buffer pH changes. Also, the effects of slaughter on the body may be so extreme that any effect that

glycolytic inhibitors may have on a living system are overwhelmed by the severity of loss of homeostasis, loss of blood, and rigor onset.

In conclusion, neither ante-mortem oral administration of citrate or acetate at 45 min before harvest nor feeding them 60 min before harvest were effective at inhibiting post-mortem glycolysis, altering pre-rigor pH, or improving pork quality. More research should be conducted to determine if earlier administration would improve their effects. Phosphofructokinase was the rate-limiting step in post-mortem glycolysis in pork, but the length of time that the rate-limiting effects last is questionable when pigs are fed before slaughter. Glycolytic inhibitors may have potential to affect post-mortem metabolism in pork, but they must reach the enzyme in time to be effective, and the inhibition must be accomplished early post-mortem.

Table 1. Mean Values For Blood pH and Bicarbonate and Lactate Concentrations of Pigs 45 min after Oral Administration (Experiment 1) and 60 min after Feeding (Experiment 2) of Sodium Citrate, Sodium Acetate, or Control Diets

	Acetate	Citrate	Control	S.E. [a]
Experiment 1				
pH	7.48	7.47	7.48	0.01
Bicarbonate (mmol/L)	37.36	37.08	37.31	0.65
Lactate (mmol/L)	2.51[bc]	3.36[b]	1.51[c]	0.45
Experiment 2				
pH	7.48	7.46	7.46	0.02
Bicarbonate (mmol/L)	34.84	33.97	34.00	1.09
Lactate (mmol/L)	2.54	2.99	3.96	0.49

[a]Largest standard errors for ante-mortem treatments.
[bc]Means lacking a common superscript letter differ ($P<0.05$).

Table 2. Mean Values and Standard Errors of Glycolytic Metabolite Concentrations from the *Longissimus*, Removed at 45 min and 3 and 12 h Post-mortem, from Pigs Given Sodium Citrate, Sodium Acetate, or Water as Control 45 min Ante-mortem (Experiment 1)

Metabolite	Treatment	45 min	3 h	12 h	Mean	S.E.[d]
Glucose-6 Phosphate (μmole/g)						
	Acetate	4.88	6.72	8.16	6.59	0.42
	Citrate	4.84	7.80	8.15	6.93	0.42
	Control	4.48	6.92	7.43	6.27	0.42
	Mean	4.73[c]	7.15[b]	7.91[a]		
	S.E.[e]	0.29	0.29	0.29		
Fructose-6 Phosphate (μmole/g)						
	Acetate	0.73	1.03	0.89	0.89	0.05
	Citrate	0.71	0.89	0.92	0.84	0.05
	Control	0.73	0.89	0.86	0.83	0.05
	Mean	0.73[b]	0.94[a]	0.89[a]		
	S.E.[e]	0.04	0.04	0.04		
Fructose-1,6 Bisphosphate (nmole/g)						
	Acetate	90.8	23.9	14.4	43.0	5.6
	Citrate	86.7	22.1	18.8	42.5	5.7
	Control	85.0	6.7	15.9	35.9	5.7
	Mean	87.5[a]	17.6[b]	16.4[b]		
	S.E.[e]	5.3	5.2	5.2		
Glyceraldehyde-3 Phosphate and Dihydroxyacetone Phosphate (nmole/g)						
	Acetate	38.6	11.1	15.9	21.9	3.4
	Citrate	46.3	11.0	18.8	25.4	3.4
	Control	33.6	6.7	8.9	16.4	3.4
	Mean	39.5[a]	9.6[b]	14.5[b]		
	S.E.[e]	3.0	3.0	3.0		
Lactate (μmole/g)						
	Acetate	9.28	11.37	11.85	10.83	0.34
	Citrate	9.26	11.58	11.44	10.76	0.34
	Control	9.33	12.75	11.45	11.18	0.34
	Mean	9.29[b]	11.90[a]	11.58[a]		
	S.E.[e]	0.34	0.34	0.34		

[abc]Means for post-mortem time means of metabolites lacking common superscript letters differ ($P<0.05$).
[d]Standard error of the ante-mortem treatment main-effect means.
[e]Standard error of the post-mortem time main-effect means.

Table 3. Mean Values and Standard Errors of Glycolytic Metabolite Concentrations from the *Longissimus*, Removed at 45 min and 3 and 12 h Post-mortem, from Pigs Fed Sodium Citrate, Sodium Acetate, or a Control Diet at 60 min Ante-mortem (Experiment 2)

Metabolite	Treatment	45 min	3 h	12 h	Mean	S.E.[d]
Glucose-6 Phosphate (μmole/g)						
	Acetate	3.92	6.37	8.68	6.32	0.32
	Citrate	4.18	7.79	9.22	7.06	0.33
	Control	4.02	7.29	8.28	6.53	0.31
	Mean	4.04[c]	7.15[b]	8.73[a]		
	S.E.[e]	0.32	0.33	0.32		
Fructose-6 Phosphate (μmole/g)						
	Acetate	0.70	1.14	1.53	1.12	0.07
	Citrate	0.83	1.49	1.52	1.28	0.07
	Control	0.76	1.35	1.40	1.17	0.07
	Mean	0.76[b]	1.32[a]	1.48[a]		
	S.E.[e]	0.07	0.07	0.07		
Fructose-1,6 Bisphosphate (nmole/g)						
	Acetate	89.4	67.8	19.5	58.9	6.3
	Citrate	75.1	58.7	19.6	51.1	6.4
	Control	78.9	68.8	11.1	53.0	6.1
	Mean	81.1[a]	65.1[b]	16.7[c]		
	S.E.[e]	5.6	5.8	5.6		
Glyceraldehyde-3 Phosphate and Dihydroxyacetone Phosphate (nmole/g)						
	Acetate	66.6	32.7	22.7	40.7	5.9
	Citrate	43.3	31.9	25.6	33.6	5.9
	Control	44.9	36.3	19.9	33.7	5.7
	Mean	51.6[a]	33.6[b]	22.7[b]		
	S.E.[e]	5.2	5.5	5.4		
Lactate (μmole/g)						
	Acetate	6.94	10.67	12.83	10.15	0.33
	Citrate	7.41	10.59	12.03	10.01	0.34
	Control	6.92	10.66	11.96	9.85	0.32
	Mean	7.09[c]	10.64[b]	12.27[a]		
	S.E.[e]	0.32	0.33	0.32		

[abc]Means for post-mortem times of metabolites with different superscript letters differ ($P<0.05$).
[d]Standard errors for the ante-mortem treatment main-effect means.
[e]Standard errors for time main-effect means.

Table 4. Mean Values and Standard Errors of Pre-rigor pH from *Longissimus* Muscle, Removed at 45 min and 3 and 12 h Post-mortem, from Pigs 45 min after Oral Administration (Experiment 1) and 60 min after Feeding (Experiment 2) of Sodium Citrate, Sodium Acetate, or Controls

Treatment	20 min	45 min	3 h	6 h	12 h	24 h	Mean	S.E.[f]
Experiment 1								
Acetate	6.17	5.92	5.53	5.50	5.50	5.46	5.68	0.04
Citrate	6.21	5.94	5.47	5.44	5.45	5.39	5.65	0.04
Control	6.20	5.95	5.39	5.41	5.44	5.44	5.64	0.04
Mean	6.19[a]	5.94[b]	5.46[c]	5.45[c]	5.46[c]	5.43[c]		
S.E. [g]	0.03	0.03	0.03	0.03	0.03	0.03		
Experiment 2								
Acetate	6.39	6.32	5.84	5.55	5.53	5.43	5.84	0.03
Citrate	6.40	6.19	5.71	5.52	5.46	5.41	5.78	0.03
Control	6.36	6.27	5.76	5.54	5.41	5.47	5.80	0.02
Mean	6.38[a]	6.26[b]	5.77[c]	5.54[d]	5.47[e]	5.43[e]		
S.E. [g]	0.02	0.02	0.02	0.02	0.02	0.02		

[abcde]Means for post-mortem time means lacking a common superscript letter differ ($P<0.05$).
[f]Standard error of the ante-mortem treatment main-effect means.
[g]Standard error of the post-mortem time main-effect means.

Table 5. Visual Evaluations, Instrumental Color, Expressible Moisture, and Ultimate pH Measurements of *Longissimus,* Inside and Outside *Semimembranosus* Muscles from Pigs Treated 45 min Ante-mortem with Sodium Acetate, Sodium Citrate, or a Water Control (Experiment 1)

		Ante-mortem Treatment			
Muscle		Acetate	Citrate	Control	S.E.[c]
Longissimus					
	Color[a]	2.91[y]	2.73[yz]	2.55[z]	0.08
	Firmness[b]	2.28	2.13	2.15	0.11
	Wetness[b]	2.38[y]	2.08[z]	2.11[z]	0.11
	L*	56.41[z]	60.34[y]	57.68[z]	0.84
	a*	3.36[yz]	4.11[y]	2.57[z]	0.43
	b*	12.36[z]	13.53[y]	12.18[z]	0.44
	Exp. moisture	21.34	23.75	23.34	1.03
	Ultimate pH	5.53	5.38	5.53	0.05
Inside *Semimembranosus*					
	Color	2.59	2.53	2.73	0.15
	Firmness	1.98	2.00	2.02	0.09
	Wetness	2.03	2.05	2.08	0.13
	L*	57.14	56.82	58.24	1.09
	a*	7.05	7.36	6.96	0.61
	b*	15.48	15.70	15.50	0.50
	Exp. moisture	22.48	20.13	19.81	0.89
	Ultimate pH	5.59	5.58	5.60	0.04
Outside *Semimembranosus*					
	Color	2.98	2.91	3.08	0.38
	Firmness	2.26	2.22	2.32	0.11
	Wetness	2.30	2.17	2.27	0.15
	L*	55.75	55.97	56.07	0.93
	a*	5.20	5.17	4.73	0.53
	b*	14.32	14.64	14.21	0.51
	Exp. moisture	20.98	21.66	20.48	1.18
	Ultimate pH	5.64	5.60	5.62	0.03

[a]Color was evaluated on a six-point scale according to official color standards from the National Pork Producers Council (1 = lightest and 6 = darkest).

[b]Firmness and wetness were evaluated separately on three-point scales (1 = softest and wettest and 3 = firmest and driest).

[c]Standard error of the means.

[yz]Means, within a row, lacking common superscript letters differ ($P<0.05$).

Table 6. Visual Evaluations, Instrumental Color, Expressible Moisture, and Ultimate pH Values of *Longissimus,* Inside and Outside *Semimembranosus* Muscles from Pigs Fed Feed Containing Sodium Acetate, Sodium Citrate, or a Control Diet at 60 min Ante-mortem (Experiment 2)

		Ante-mortem Treatment			
Muscle		Acetate	Citrate	Control	S.E.[c]
Longissimus					
	Color[a]	3.73	3.56	3.77	0.17
	Firmness[b]	2.53[y]	2.20[z]	2.45[y]	0.13
	Wetness[b]	2.34[y]	1.97[z]	2.38[y]	0.18
	L*	52.32	53.48	54.11	0.87
	a*	3.32	3.43	3.07	0.38
	b*	11.58	12.10	11.94	0.44
	Exp. moisture	23.43	25.12	23.84	1.39
	Ultimate pH	5.56[y]	5.43[z]	5.54[y]	0.05
Inside *Semimembranosus*					
	Color	3.58	3.26	3.57	0.30
	Firmness	2.01	1.91	2.10	0.10
	Wetness	2.15	1.98	2.10	0.14
	L*	54.97	56.44	55.77	1.40
	a*	7.51	7.93	7.57	0.46
	b*	15.73	16.15	15.85	0.54
	Exp. moisture	18.86	20.13	20.74	1.36
	Ultimate pH	5.50	5.46	5.53	0.04
Outside *Semimembranosus*					
	Color	3.20	3.00	2.98	0.35
	Firmness	2.50	2.52	2.55	0.11
	Wetness	2.39	2.20	2.37	0.19
	L*	54.05	55.15	54.74	0.58
	a*	4.41	5.45	4.68	0.30
	b*	13.78	14.50	13.96	0.33
	Exp. moisture	16.17	19.13	19.49	1.09
	Ultimate pH	5.54	5.46	5.51	0.04

[a]Color was evaluated on a six-point scale according to official color standards from the National Pork Producers Council (1999, 1 = lightest and 6 = darkest).

[b]Firmness and wetness were evaluated separately on three-point scales (1 = softest and wettest and 3 = firmest and driest).

[c]Largest standard error for the means.

[yz]Means, within a row, lacking common superscript letters differ ($P<0.05$).

EFFECTS OF PRE-RIGOR INJECTION OF SODIUM CITRATE OR ACETATE, OR POST-RIGOR INJECTION OF PHOSPHATE PLUS SALT, ON POST-MORTEM GLYCOLYSIS, PH DECLINE, AND PORK QUALITY ATTRIBUTES

J. W. Stephens, M. E. Dikeman, J. A. Unruh, M. D. Haub[1], and M. D. Tokach

Summary

Forty pork carcass sides were assigned to one of four treatments: pre-rigor citrate (CIT) or acetate (ACE) injection, post-rigor phosphate plus salt (PHOS) injection, and non-injected control (CON). Loins in 20 sides were injected 50 min post-mortem with 4% solutions of CIT or ACE to approximately 110% of projected loin weights, and 10 PHOS-treated loins were injected at 24 h post-mortem to 106.6% with a 4.4% PHOS plus 2.2% salt solution. Although CIT increased pH ($P<0.05$), neither CIT nor ACE altered ($P>0.05$) glycolytic metabolite concentrations. The pH increase in CIT-injected muscle was most likely due to its buffering ability rather than glycolytic inhibition. Citrate improved tenderness without the detrimental effects on color or flavor found with PHOS plus salt, but neither CIT nor ACE altered glycolytic metabolites or improved firmness, wetness, or fresh visual color over CON. Poor flavor attributes of the ACE treatment will discourage its use as an ingredient for pork enhancement solutions.

(Key Words: Pork, Pre-rigor Injection, Citrate, Acetate, Phosphate.)

Introduction

Improving pork quality traits, such as tenderness, juiciness, and flavor, is a common goal in the pork industry. Great strides have been made to improve handling conditions and to alter genetics to remove stress susceptibility, but pork quality defects have been estimated to cost the industry an average of $2.13 per carcass. It is now common practice to 'enhance' pork with solutions of phosphate, salt, and various other ingredients. Although these solutions have been shown to improve tenderness and juiciness, they concomitantly induce some negative consequences in flavor and consumer acceptability.

Pork quality is highly dependant on the relationship of pH and temperature early post-mortem. Anaerobic glycolysis is responsible for pH decline in post-mortem muscle. The lack of oxygen and absence of a circulatory system from exsanguination, leads to myocellular accumulation of lactate and hydrogen ions. If glycolysis occurs at an accelerated rate, pH declines too rapidly and muscle proteins denature due to the combination of low pH and high temperature.

Citrate is recognized for its glycolysis-inhibiting properties; it inhibits the glycolytic enzyme, phosphofructokinase (PFK). This enzyme regulates the transfer of a phosphate from adenosine triphosphate (ATP) to fructose-6 phosphate (F6P), producing adenosine diphosphate (ADP) and fructose-1,6 bisphosphate (F16BP). It has been identified as a key

[1]Department of Human Nutrition.

regulatory enzyme of glycolysis in post-mortem muscle.

In previous research, injecting pork loins 1 h post-mortem with a solution of citrate, phosphate, and salt increased ultimate pH values and improved color, cook loss, and shear force, compared with phosphate and salt-injected controls. Sodium citrate has been used as a glycolysis inhibitor in beef muscle to improve tenderness. Sodium citrate and sodium acetate have been used to improve tenderness in beef without detrimental impact on flavor attributes.

The objective of our study was to determine the effects of pre-rigor injection of pork carcasses with sodium citrate or acetate, or post-rigor injection of phosphate plus salt, on post-mortem glycolysis, pH decline, and pork quality attributes, including display life and attributes scored by a sensory panel.

Procedures

Pigs and Treatments. Two replicates of 10 pigs were fed finishing diets containing ractopamine for at least 14 d before harvest. Pigs were weighed and assigned to pairs of similar weights. The four sides from each pair of pigs were assigned to one of four treatments: pre-rigor citrate (CIT) injection, pre-rigor acetate (ACE) injection, post-rigor phosphate plus salt injection (PHOS), and non-injected control (CON).

Harvest. Twenty hours before harvest, pigs were fasted and transported to the Kansas State University Meat Laboratory. Pairs of pigs were harvested in random order. Pigs were stunned with both an electric stunning wand and a captive bolt stunner. After stunning, pigs were exsanguinated and harvested according to normal procedures. After the carcasses were split and washed, each side was weighed.

Pre-rigor Injection. At approximately 50 min post-mortem, loins in the sides assigned to CIT and ACE treatments were injected with a 4% solution of CIT or ACE in distilled water. A hand-held injector fitted with five 10-cm injection needles was used to inject the solutions. Before injection, the skin was sliced perpendicular to the length of the loin at approximately 3-cm intervals to allow the injection needles to penetrate the skin and into the *longissimus* muscle. The loins were injected from a point beginning opposite the last lumbar vertebrae to a point immediately posterior to the scapula. The solutions were injected at room temperature; injection-solution temperature was recorded for each side to ensure uniformity. Sides were weighed again, and pump percentage was calculated. It was assumed that the loin was 20% of the total side weight, and that only the loin absorbed the solution. The estimated injection percentage of the loins injected pre-rigor was 10%.

To monitor temperature decline, a temperature logger was placed in the *longissimus* muscle of each side. A slice was made at the sirloin-loin juncture, and the temperature probe was inserted into the muscle at least 2.75 inches, at a 45-degree angle to the skin surface. After injection, a muscle sample was removed from the anterior portion of the injected *longissimus* from both sides of the carcasses. The muscle samples were cubed, quick-frozen in liquid nitrogen, packaged, temporarily stored on dry ice, and stored at –80^{o}C for pre-rigor pH and glycolytic metabolite analysis. Additional muscle samples were removed from the *longissimus* muscle of each side at 3, 6, 12, and 24 h post-mortem and frozen in liquid nitrogen as previously described. At least 1.5 inch of muscle was maintained between muscle sample locations, to minimize the effects of chilling rate on the cut surfaces.

Pre-rigor pH Analysis. Frozen muscle samples were pulverized into a powder and

stored at -80°C until analysis for pre-rigor pH and glycolytic metabolites. Duplicate 5-g samples of powdered muscle were mixed with 50 ml of a solution of iodoacetate in 150 mM potassium chloride. The mixture was covered with Parafilm and allowed to acclimate to room temperature for no less than 4 h. After acclimation, the solution was remixed, and each duplicate was read twice by using two pH probes with a portable meter.

Glycolytic Metabolites. Samples from 50 min, 3 h, and 12 h were analyzed for glucose-6 phosphate (G6P), fructose-6 phosphate (F6P), fructose-1,6 bisphosphate (F16BP), a combination of glyceraldehyde-3 phosphate and dihydroxyacetone phosphate (GAPDAP), and lactate.

Fabrication and Post-rigor Injection. At 24 h post-mortem, loins were removed from the sides; the anterior section, where the muscle samples were removed, was discarded. Loins assigned to CIT, ACE, and CON treatments were vacuum packaged and stored at 1°C. Loins assigned to post-rigor PHOS treatment were injected with a solution containing 4.4% sodium tripolyphosphate and 2.2% sodium chloride by using the hand-stitch injector used for the CIT and ACE treatments. After two rounds of PHOS injection, the loins had absorbed 6.6% of their pre-injected weight. After injection, the loins assigned to PHOS were vacuum packaged and stored overnight at 1°C. The loins were re-weighed after vacuum storage and found to retain 104.6% of their pre-injected weight.

Chop Removal, Initial Pork Color, Firmness, and Wetness. At 2 d post-mortem, loin sections were de-boned, and three 2.54-cm chops were removed from the posterior section of the *longissimus*. One chop, for sensory-panel analysis, was vacuum packaged and stored at 1°C for 8 d before freezing at –20°C. An additional chop was vacuum packaged and stored at 1°C overnight for pH and expressible moisture-analysis. The third chop was allowed to bloom for no less than 30 min and was evaluated by a three-member, trained visual panel for color, firmness, and wetness. Color was evaluated according to the official NPPC color standard cards (1 = lightest and 6 = darkest). Firmness and wetness were evaluated separately by using three-point scales (1 = softest or wettest and 3 = firmest or driest).

Display Color. Chops for visual evaluation were packaged in white foam trays with absorbent pads, over-wrapped with PVC film, and placed in an open-top display case under continuous fluorescent lighting. A trained visual panel of no fewer than six persons evaluated color each day over 7 d of display. Panelists scored each chop for color on a six-point scale (1 = extremely bright pink, 2 = bright pink, 3 = dull pink, 4 = slightly dark pink or tan, 4.5 = borderline panelist unacceptable, 5 = moderately dark pink or tan, 6 = dark pink or tan) and scored for discoloration on a seven-point scale (1 = no discoloration (0%), 2 = slight discoloration (1 to 19%), 3 = small discoloration (20 to 39%), 4 = modest discoloration (40 to 59%), 5 = moderate discoloration (60 to 79%), 6 = extensive discoloration (80 to 99%), 7 = total discoloration (100%)). The scores for each d were averaged for analysis.

Display Loss. After display, packages were weighed. Chops were removed, dabbed with a paper towel, allowed to dry for 5 min, and weighed again to calculate display loss, calculated as follows: [(pre-display weight – post-display weight)/pre-display weight] × 100.

Instrumental Color. Each day of display, a HunterLab Miniscan XE Plus spectrophotometer was used to obtain L*, a*, and b* values on the over-wrapped chops. Each chop was measured twice with a 3.2-cm aperture, a

10^o observer, and illuminant D_{65}. Readings were averaged for analysis.

Expressible Moisture. At 3 d post-mortem, chops assigned to expressible-moisture evaluation were removed from their vacuum bags. A scapel and tweezers were used to remove duplicate samples (2 to 3 g) parallel to the muscle fiber direction, from the interior of the chop. The rest of the chop was vacuum packaged and stored at 1^oC until pH analysis. Samples were weighed and placed in a 50-ml centrifuge tube fitted with one piece of Whatman No. 3 filter paper folded around one piece of Whatman No. 50 filter paper. The tubes were capped and centrifuged at 2100 rpm for 10 min. After centrifugation, samples were weighed again, and expressible moisture was calculated.

Ultimate pH Analysis. Duplicate samples (10 g each) were minced with a scalpel. Samples were placed in a filtered stomacher bag with 100 ml of distilled water and stomached for 2 min. After stomaching, pH was measured.

Evaluations by Trained Sensory Panel. Chops for analysis by a trained sensory panel were stored frozen for 3 months and thawed overnight at 4^oC. Chops were cooked to 70^oC, and temperature was monitored. After cooking, the outer connective tissue was removed, and the chops were cut into cubes and held in pre-heated double broilers. No fewer than six trained panelists were seated in an environmentally controlled room. Two cubes from each chop were served to panelists in a statistically randomized order, and a score was determined by using an 8-point scale to the nearest 0.5. Scores were determined for myofibrillar tenderness (1 = extremely tough, 8 = extremely tender), juiciness (1 = extremely dry, 8 = extremely juicy), pork flavor intensity (1 = extremely intense pork flavor, 8 = extremely bland), connective tissue amount (1 = abundant, 8 = none), overall tenderness (1 = extremely tough, 8 = extremely tender), and off-flavor intensity (1 = abundant, 8 = none).

Statistical Analysis. Muscle temperature data were analyzed as an incomplete block with repeated measures, with individual pig as the block. Pre-rigor pH and glycolytic metabolite data were analyzed in a split-plot design, with injection treatment as the whole plot and time post-mortem as the subplot. Pig was used as the block in the whole plot. Visual color, firmness, wetness, expressible moisture, and ultimate pH were analyzed in an incomplete block, with pig as the block. Visual- and instrumental-display data were analyzed in an incomplete-block design, with the repeated measure of time and pig as the block. Data from the sensory panel were analyzed in an incomplete-block design, blocking on pig and panelist. Injection treatment and time post-mortem were treated as fixed effects; pig and panelist were treated as random effects. Data were analyzed by using PROC MIXED in the Statistical Analysis System; means were separated by using the PDIFF test when $P<0.05$. For repeated-measures analysis, the Repeated Measures command was used with the autoregressive option.

Results and Discussion

Temperature. At 1 h post-mortem, *longissimus* muscles from carcasses not injected were warmer ($P<0.05$) than those from CIT- and ACE-injected carcasses, and those from ACE-injected carcasses were warmer ($P<0.05$) than those from CIT-injected carcasses (Figure 1). Nevertheless, muscle temperatures among treatments were similar ($P>0.05$) for measurements taken in 1-h increments afterwards. It is probable that the temperature of the injection solution lowered the temperature of the muscle in the first few minutes after injection, but did not affect chill rate after 1 h.

Pre-rigor pH. There was no time × treatment interaction ($P>0.05$) for pre-rigor pH (Table 1). *Longissimus* muscles from CIT-injected carcasses had the highest ($P<0.05$) pre-rigor pH values, whereas those from ACE-injected carcasses did not differ ($P>0.05$) from CON and PHOS-injected carcasses. The pH was highest ($P<0.05$) at 50 min post-mortem, and values at 3, 6, 12, and 24 h were similar ($P>0.05$), indicating that the majority of pH decline occurred before 3 h.

Glycolytic Metabolites. A time × injection treatment interaction ($P<0.05$) was found for G6P concentration (Figure 2). All four treatments resulted in similar ($P>0.05$) G6P concentrations at 50 min post-mortem. Values for G6P in CON muscles increased ($P<0.05$) with post-mortem time, and were higher ($P<0.05$) than for CIT- and ACE-injected muscles at 3 and 12 h post-mortem. In muscles designated for post-rigor PHOS injection, 12-h concentrations of G6P were higher ($P<0.05$) than those at 50 min, and 3-h concentrations were intermediate. Concentrations of G6P from *longissimus* muscles designated for PHOS injection were higher ($P<0.05$) than those from CIT-injected muscles at 3 h, but were similar to those from CIT- and ACE-injected muscles at 12 h. Concentrations of G6P from ACE- and CIT-injected *longissimus* muscles were similar ($P>0.05$) at 50 min and 3 h. The 12-h G6P concentrations were higher than 50-min and 3-h concentrations in ACE-injected muscles, but only higher than the 3-h samples in CIT-injected carcasses. No interaction existed for F6P values ($P>0.05$; Figure 3). The CON and PHOS-injected muscles had higher concentrations ($P<0.05$) of F6P than those from ACE- and CIT-injected muscles did. Concentrations of F6P were similar ($P>0.05$) at 50 min and 3 h, but were higher ($P<0.05$) at 12 h.

Glucose-6 phosphate is the precursor to F6P, which is a substrate for PFK. Successful inhibition of PFK by CIT and ACE treatments should have resulted in elevated concentrations of G6P and F6P. Nevertheless, G6P and F6P concentrations were highest ($P<0.05$) for CON and PHOS-injected treatments, indicating that CIT and ACE injection activated PFK activity, rather than inhibited it. Citrate increases the enzyme's affinity for ATP at the substrate site and activates the reaction. Reactions of rigor take place due to a drop in ATP concentration; pre-rigor CIT injection, in combination with low ATP concentrations associated with rigor, may have actually activated PFK. Although previous researchers have not observed this phenomenon in post-mortem beef muscle, pork is inherently more glycolytic than beef and goes into the rigor state at an earlier time post-mortem. It is possible that the approximately 10% addition of water diluted G6P and F6P concentrations in the ACE- and CIT-injected *longissimus* muscles, but this dilution effect was not evidenced in other metabolites.

A time × treatment interaction ($P<0.05$) was found for F16BP values (Figure 4). At 50 min post-mortem, concentrations of F16BP in samples from CIT-injected muscles were lower ($P<0.05$) than those from CON. Concentrations of F16BP from CIT-injected muscles were higher than those from ACE-injected muscles at 3 h, and those from CON and PHOS were intermediate. Levels were similar for all treatments at 3 and 12 h. For CON, PHOS-injected, and ACE-injected muscles, the 50-min concentrations were higher ($P<0.05$) than at 3 and 12 h. For CIT-injected muscles, 50-min and 3-h F16BP concentrations were similar ($P>0.05$) and greater than 12-h ($P<0.05$) concentrations, but concentrations were similar to those from CON and PHOS-injected muscles at 3 and 12 h. There was a time × treatment interaction ($P<0.05$) for GAPDAP concentrations (Figure 5). *Longissimus* muscles designated for PHOS injection had larger ($P<0.05$) GAPDAP values than those from ACE-injected muscles did at

50 min; all other treatments were similar. All treatments were similar at 3 and 12 h post-mortem. The 50-min concentrations were highest ($P<0.05$), and the 3- and 12-h concentrations were similar ($P>0.05$) for all treatments.

The product of PFK is F16BP; inhibition of PFK should have resulted in decreased concentrations of F16BP for CIT- and ACE-injected muscles. Maintenance of high concentrations of F16BP at 3 h for CIT-injected muscles could indicate that F16BP was being replenished by PFK as it was used, and that the PFK was activated rather than inhibited. The F16BP concentrations from CON, PHOS-injected, and ACE-injected muscles were not being replenished. Aldolase, the enzyme that cleaves F16BP to form GAP and DAP, operates continuously in the presence of substrate, F16BP. Therefore, GAPDAP concentrations indicate PFK activity. Our data indicate that GAPDAP concentrations were not being replenished by PFK for any treatment.

There was no interaction ($P>0.05$) for lactate concentrations (Figure 6). Muscles that were injected with CIT had lower ($P<0.05$) lactate concentrations than those designated for 24-h PHOS injection did, but CON and ACE-injected muscles were not different ($P > 0.05$) in lactate concentration than those from CIT- and PHOS-injected muscles. Lactate concentrations increased ($P<0.05$) as post-mortem time increased; and this was expected because lactate accumulates with time.

Glycolytic metabolite data indicate that CIT and ACE were ineffective as glycolytic inhibitors when injected into pork muscle, even though CIT-injected muscles had higher pre-rigor pH. The CIT solution likely increased muscle pH due to its buffering capacity and multiple negative charges on the citrate ion. Others have found that pre-rigor injection of beef muscles with CIT inhibited glycolysis, as evidenced by increased muscle pH and glycogen levels. Glycogen levels were not measured in our study. In other research, PFK was thought to be inactivated within 20 min post-mortem and not affect pork quality attributes. Nevertheless, others have stated that PFK is the main rate-limiting enzyme in post-mortem muscle glycolysis. Our research indicated that PFK was still active in the muscle after 50 min post-mortem when the CIT and ACE solutions were introduced into the muscle system, because the glycolytic metabolites were still changing after 50 min post-mortem. Concentrations of ATP may have been at a non-saturated state at an earlier time post-mortem, and PFK may have been activated by CIT injection, as discussed earlier. In past research, CIT has been found to be inhibitory in pork, but that injection solution included phosphate and salt, which would have drastically affected muscle pH. Enzyme activities are altered at higher pH. Furthermore, the increase in ionic strength due to the phosphate and salt may have affected the PFK activity.

Pork Quality Attributes. Mean values for visual color, firmness, and wetness, as well as expressible moisture, ultimate pH, and display loss, are presented in Table 2. According to visual panelists, chops from ACE- and CIT-injected carcasses were less firm ($P<0.05$) and wetter ($P<0.05$) than those from CON and PHOS-injected carcasses. These inferiorities were not surprising because the CIT- and ACE-injection treatments added approximately 10% water to the *longissimus* muscle. Chops from PHOS-injected carcasses also had added water, but the percentage was lower than for CIT- and ACE-injected carcasses, and PHOS injection greatly increased ($P<0.05$) muscle pH. Chops from PHOS-injected carcasses had the highest ($P<0.05$) ultimate pH values, and chops from CIT-injected carcasses had higher ($P<0.05$) ultimate pH values than those from CON or ACE-injected carcasses. Chops from CIT- and ACE-injected carcasses

had greater (P<0.05) display losses than those from PHOS and CON treatments had. Chops from PHOS-injected carcasses had the least (P<0.05) display loss. Visual color and expressible moisture were not affected by injection treatment.

Display Evaluations. Visual color scores increased (P<0.05) throughout display for all four treatments, indicating a deterioration of color during display (Figure 7). Chops from PHOS-injected carcasses had the highest (darkest; P<0.05) visual scores each day of display, compared with those of other treatments. Chops from PHOS-injected carcasses were considered unacceptable (color scores greater than 4.5) by the panelists after 5 d of display; no other treatment reached that mark. Chops from ACE- and CIT-injected carcasses were similar (P>0.05) to those from CON carcasses each day of display. Although discoloration scores for chops from PHOS-injected carcasses were similar (P>0.05) to those from CON carcasses for the first 2 d of display, they were higher (P<0.05) than scores from other treatments throughout the rest of the display period (Figure 8). Chops from ACE-injected carcasses were similar (P>0.05) to those from CON carcasses in discoloration scores throughout display. For the first 6 d of display, chops from CIT-injected carcasses were similar (P>0.05) to those from CON carcasses, but on the final day of display, the discoloration scores were higher (P<0.05) for chops from CIT-injected carcasses than for chops from CON carcasses.

Chops from PHOS-injected loins were darkest (smallest L* values; P<0.05) throughout display. Although chops from ACE-injected carcasses were similar (P>0.05) to those from CON carcasses for the first 2 d of display, they were lighter (P<0.05) than those from CON for the last 5 d of display (Figure 9). Chops from CIT-injected carcasses were similar (P>0.05) to those from CON carcasses in L* value throughout the display period. Chops from CIT-injected carcasses did not change (P>0.05) throughout display, whereas L* values for chops from PHOS-injected and CON carcasses peaked (P<0.05) after 1 d of display.

Chops from PHOS-injected carcasses were less red (smaller a* value; P<0.05) than those from CON and ACE-injected carcasses each day of display (Figure 10). Chops from CIT-injected carcasses were similar (P>0.05) to those from PHOS-injected carcasses on d 0 and the final 2 d of display. Chops from CON carcasses were similar to those from ACE-injected carcasses on the first 2 d of display, and similar to chops from CIT-injected carcasses after 1 d, but they had the largest a* values (P<0.05) the final 5 d of display. Chops from ACE-injected carcasses were redder (P<0.05) than those from CIT-injected carcasses on d 0 and 2, but they were similar (P>0.05) throughout the rest of display. Previous research found that pork chops from CIT-injected loins had larger a* values than phosphate-injected controls did, but that CIT treatment also included phosphate.

Chops from PHOS-injected carcasses had the smallest b* values (least yellow; P<0.05) throughout display (Figure 11); chops from CIT- and ACE-injected carcasses were similar (P>0.05) to those from CON carcasses throughout display. Chops from PHOS-injected carcasses had the smallest b* values on d 0, but values for b* did not notably change (P>0.05) over time for any of the other treatments. Previous research in beef found that CIT-injected samples were less yellow than controls, whereas ACE-injected samples were similar to controls.

Sensory Attributes. Values for attributes evaluated by the trained sensory panel are displayed in Table 3. Control chops were toughest (P<0.05), chops from PHOS-injected car-

casses were most tender ($P<0.05$), and the treatments injected pre-rigor were intermediate in both myofibrillar and overall tenderness. Control chops also had the lowest ($P<0.05$) connective tissue scores, indicating a higher percentage of detectable connective tissue. The increase in tenderness of chops from PHOS-injected carcasses may have been partly due to the swelling of myofibrils caused by phosphate and salt and to the dilution of the proteins by the injection solutions. In other research, chops from CIT-injected loins had lower shear force values than CON.

Chops from PHOS-injected carcasses were also juiciest ($P<0.05$), whereas chops from CIT- and ACE-injected carcasses were similar ($P>0.05$) to those from CON carcasses. The increase in ultimate pH, resulting in improved water holding capacity, by the PHOS injection likely was responsible for the improved juiciness of that treatment.

Chops from CON and CIT-injected carcasses had higher ($P<0.05$) pork flavor intensity scores and less incidence ($P<0.05$) of off-flavors than those from PHOS- and ACE-injected carcasses. It is likely that the off-flavors associated with the PHOS- and ACE-injected treatments masked the pork flavor of the chops. The most common off-flavor descriptor for chops from PHOS-injected carcasses was salty. Other off-flavor descriptors of soapy, metallic, rancid, and acidic, were also used to describe the chops from PHOS-injected carcasses. Chops from ACE-injected carcasses were most commonly described as sweet or sugary, as well as acidic, lemony, or vinegary. Other, infrequent off-flavor descriptors for chops from ACE-injected carcasses included chemical, soapy, salty, metallic, cleaner fluid, and Tabasco. Although chops from CIT-injected and CON carcasses had less incidence ($P<0.05$) of off-flavors than ACE- and PHOS-injected carcasses had, some descriptors were provided. Chops from CIT-injected carcasses were infrequently described as acidic, metallic, salty, bitter, and rancid, whereas those from CON carcasses were described as acidic, bitter, salty, and metallic.

Glycolytic-metabolite data indicated that the increase in pH in CIT-injected muscle was not due to an inhibition of glycolysis post-mortem. The pH increase in the muscle was likely due to the relatively high pH of the citrate solution. The very glycolytic conditions of pork muscle and low ATP levels during rigor may have overwhelmed citrate's ability to inhibit glycolysis. The data reinforced the evidence for rate-limiting effects of PFK in post-mortem muscle.

Although pre-rigor CIT injection increased pH and improved tenderness, compared with CON, visual firmness and wetness were decreased with CIT injection. Chops from CIT-injected carcasses were similar to those from CON carcasses in pork-flavor intensity, and there were no excessive off-flavors. Perhaps using CIT in conjunction with a phosphate and salt solution would allow for improved muscle water-holding capacity, and the water-soluble CIT in the injection-solution would be more accessible to PFK.

Chops from ACE-injected carcasses were superior to those from CON carcasses in tenderness, but glycolytic-metabolite and pH data indicated that ACE did not inhibit post-mortem glycolysis. Furthermore, the decreased pork-flavor intensity and objectionable off-flavors of ACE injection likely will discourage use of this compound at this concentration in injection solutions for fresh meat.

Table 1. Mean Values for Pre-rigor pH of *Longissimus* Muscle From Carcasses Injected 50 min Post-mortem with Sodium Citrate or Sodium Acetate, Non-Injected Control Carcasses, and Carcasses Designated for 24 h Injection with Phosphate + Salt

	Pre-rigor Injection		Non-injected	Injected at 24 h	
Time	Acetate	Citrate	Control	Phosphate + Salt	Mean[c]
50 min	5.87	5.96	6.00	5.90	5.93[a]
3 h	5.45	5.58	5.49	5.49	5.51[b]
6 h	5.52	5.56	5.49	5.47	5.51[b]
12 h	5.49	5.52	5.46	5.44	5.48[b]
24 h	5.50	5.55	5.47	5.48	5.50[b]
Mean	5.57[b]	5.63[a]	5.58[b]	5.56[b]	

[ab]Means for times and treatments lacking common superscript letters differ ($P<0.05$).
[c]Standard error for all means = 0.02.

Table 2. Visual Evaluations, Expressible Moisture, Ultimate pH, and Display Loss Measurements of *Longissimus* Chops from Pork Carcasses Injected 50 min Post Mortem with Sodium Acetate or Sodium Citrate, Non-injected Controls, or 24 h Injection with Phosphate + Salt

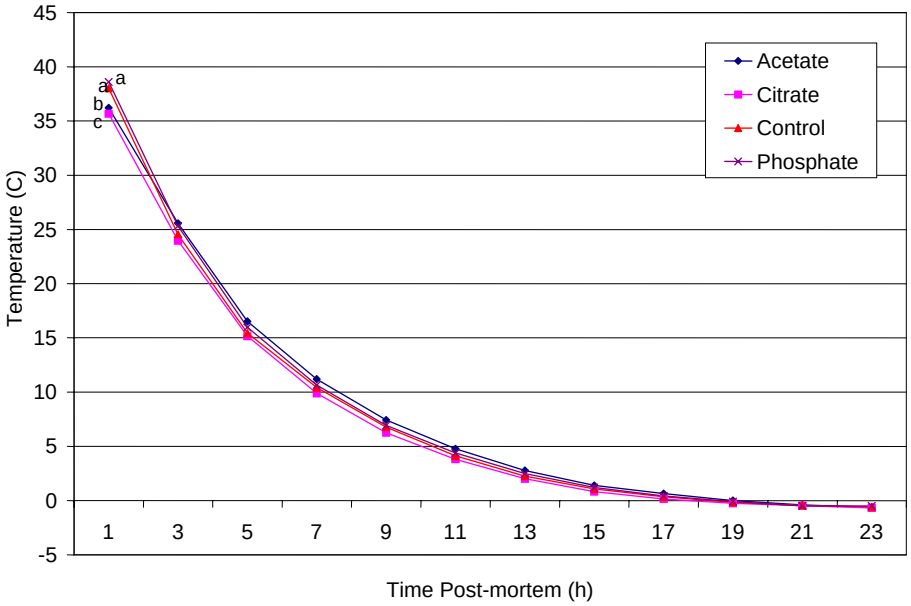
	Pre-rigor Injection		Non-injected	Injected at 24 h	
Item	Acetate	Citrate	Control	Phosphate + Salt	S.E.[c]
Color[a]	3.26	3.16	4.48	4.33	0.53
Firmness[b]	1.95[y]	2.14[y]	2.36[z]	2.49[z]	0.15
Wetness[b]	1.93[y]	1.96[y]	2.46[z]	2.41[z]	0.18
Expressible moisture	18.87	20.01	20.14	18.56	1.35
Ultimate pH	5.51[x]	5.63[y]	5.48[x]	5.99[z]	0.03
Display loss	9.36[z]	9.71[z]	7.45[y]	4.73[x]	0.58

[a]Color was evaluated on a 6-point scale according to official color standards from the National Pork Producers Council (1 = lightest and 6 = darkest).
[b]Firmness and wetness were evaluated separately on 3-point scales (1 = softest and wettest and 3 = firmest and driest).
[c]Standard error.
[xyz]Means, within a row, lacking common superscript letters differ ($P<0.05$).

Table 3. Mean Values and Standard Errors for Trained Sensory Panel Traits for *Longissimus* Chops from Carcasses Injected with Sodium Citrate or Sodium Acetate 50 min Postmortem, Non-injected Controls, and Injection with Phosphate + Salt at 24 h

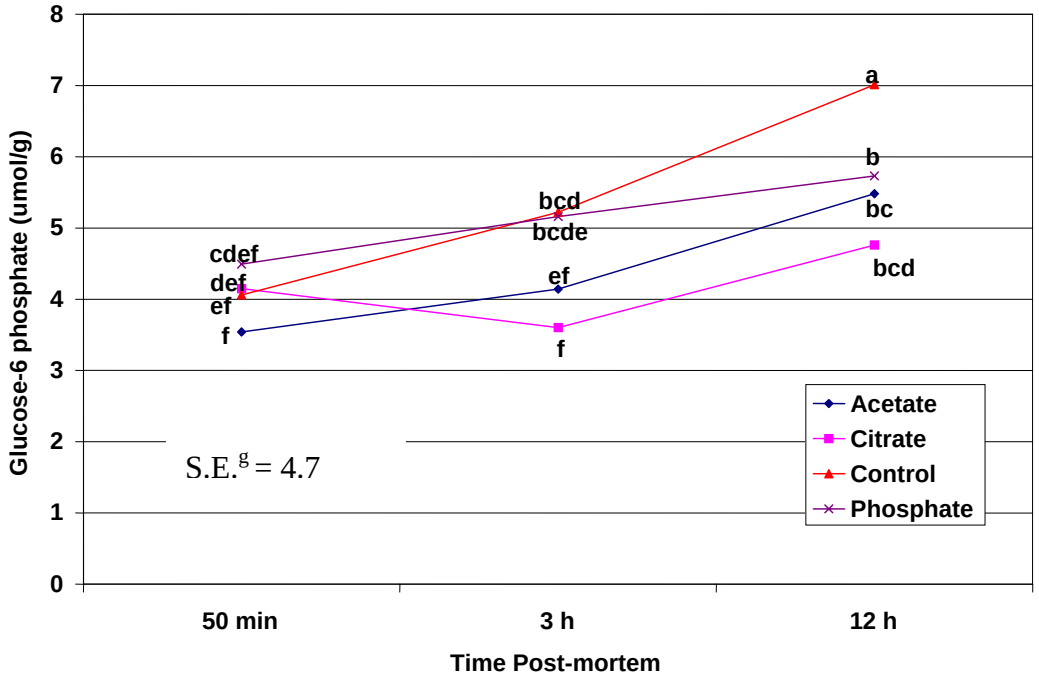
	Pre-rigor Injection		Non-injected	Injected at 24 h	
Item	Acetate	Citrate	Control	Phosphate + Salt	S.E.[f]
Myofibrillar tenderness[a]	5.78[y]	5.83[y]	4.81[z]	6.34[x]	0.19
Juiciness[b]	5.12[z]	4.99[z]	4.83[z]	6.17[y]	0.15
Pork flavor intensity[c]	4.56[z]	5.22[y]	5.19[y]	4.83[z]	0.22
Off flavor[d]	5.42[z]	7.52[y]	7.09[y]	5.30[z]	0.24
Connective tissue[e]	7.34[y]	7.38[y]	6.94[z]	7.42[y]	0.14
Overall tenderness	6.02[y]	6.13[y]	5.10[z]	6.61[x]	0.18

[a]Myofibrillar tenderness and overall tenderness were evaluated on an 8-point scale (1 = extremely tough and 8 = extremely tender).
[b]Juiciness was evaluated on an 8-point scale (1 = extremely dry and 8 = extremely juicy).
[c]Pork flavor intensity was evaluated on an 8-point scale (1 = extremely bland and 8 = extremely intense pork flavor).
[d]Off flavor was evaluated on an 8-point scale (1 = abundant and 8 = none).
[e]Connective tissue amount was evaluated on an 8-point scale (1 = abundant and 8 = none).
[f]Standard error.
[xyz]Means, within a row, lacking common superscript letters differ ($P<0.05$).



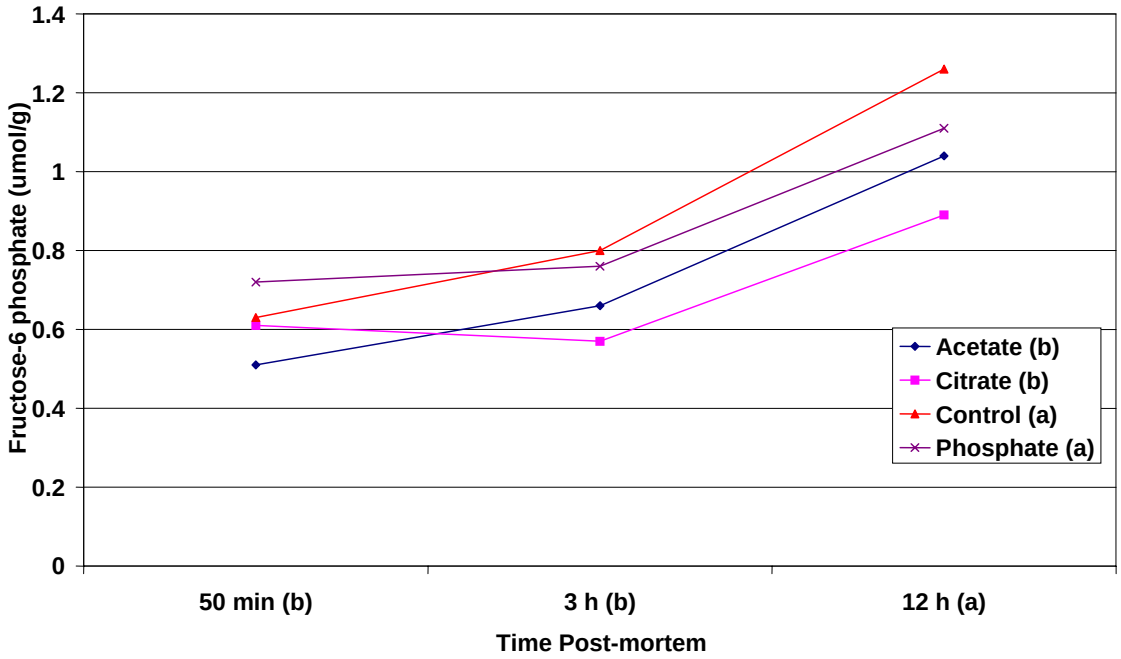
[abc] Data points, for the first temperature reading, lacking common superscript letters differ ($P<0.05$).

Figure 1. Mean *Longissimus* muscle Temperatures of Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



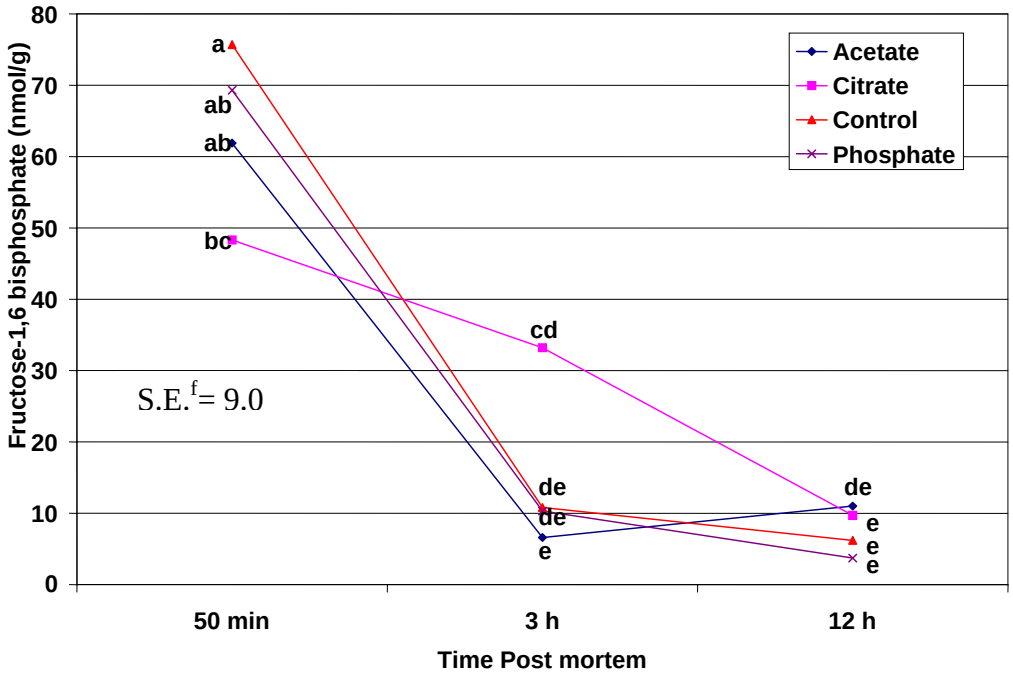
[abcdef]Means lacking common superscript letters differ ($P<0.05$).
[g]Largest interaction mean standard error.

Figure 2. Mean Concentrations of Glucose-6 Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



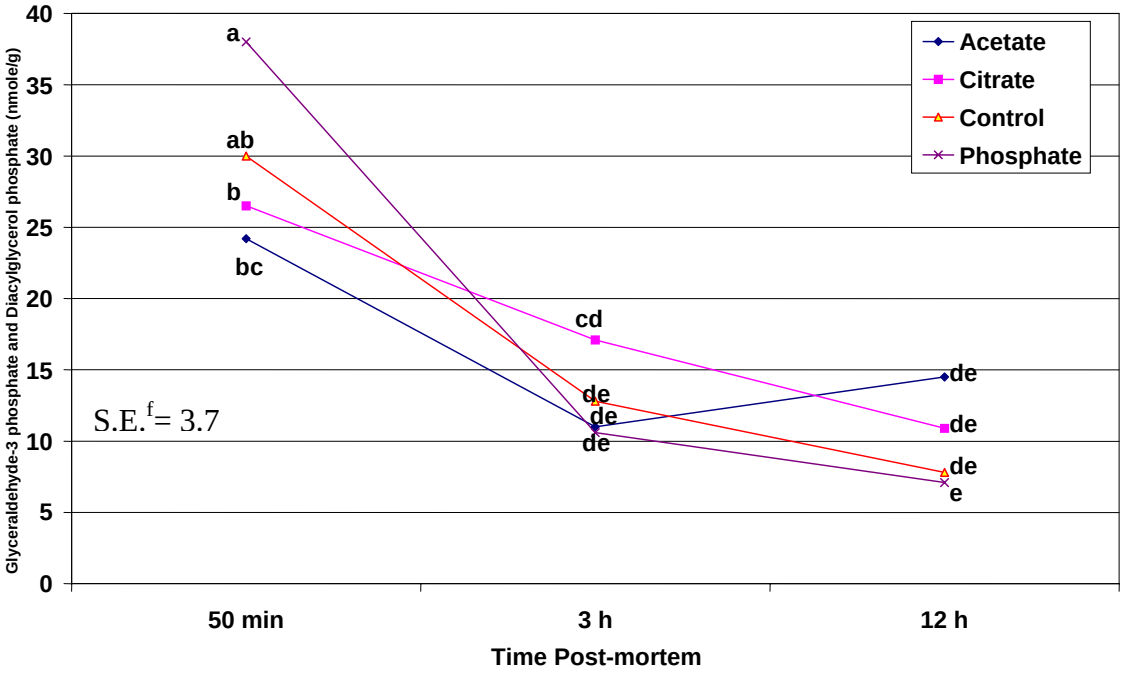
[ab]Main effect means lacking common superscript letters (in parenthesis) differ ($P<0.05$),
Standard error for ante mortem treatment main effects = 0.06,
Standard error for time main effects = 0.05

Figure 3. Mean Concentrations of Fructose-6 Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Postmortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



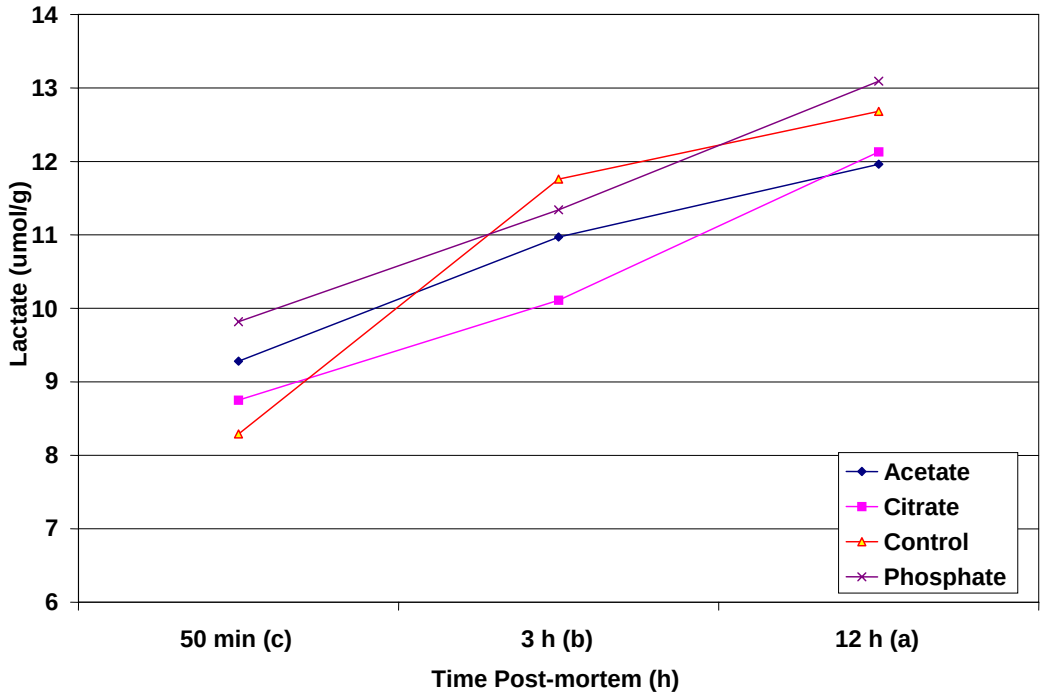
[abcde]Means lacking common superscript letters differ ($P < 0.05$).
[f]Largest standard error for interaction means.

Figure 4. Mean Concentrations of Fructose-1,6 Bisphosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



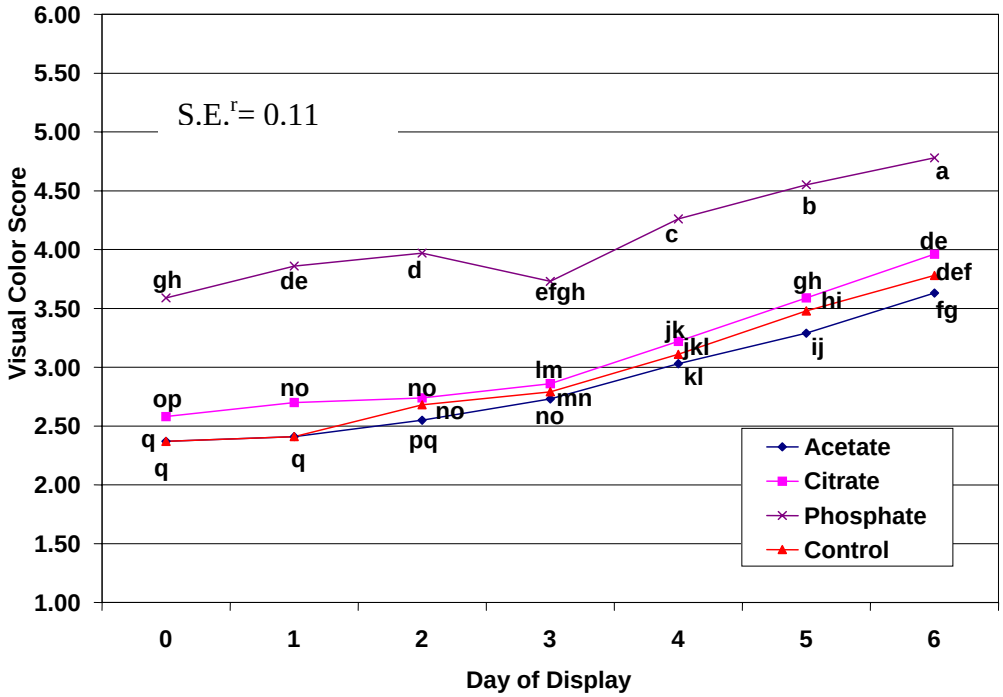
[abcde]Means lacking common superscript letters differ ($P < 0.05$).
[f]Largest standard error for interaction means.

Figure 5. Mean Concentrations for a Combination of Glyceraldehyde-3 Phosphate and Dihydroxyacetone Phosphate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



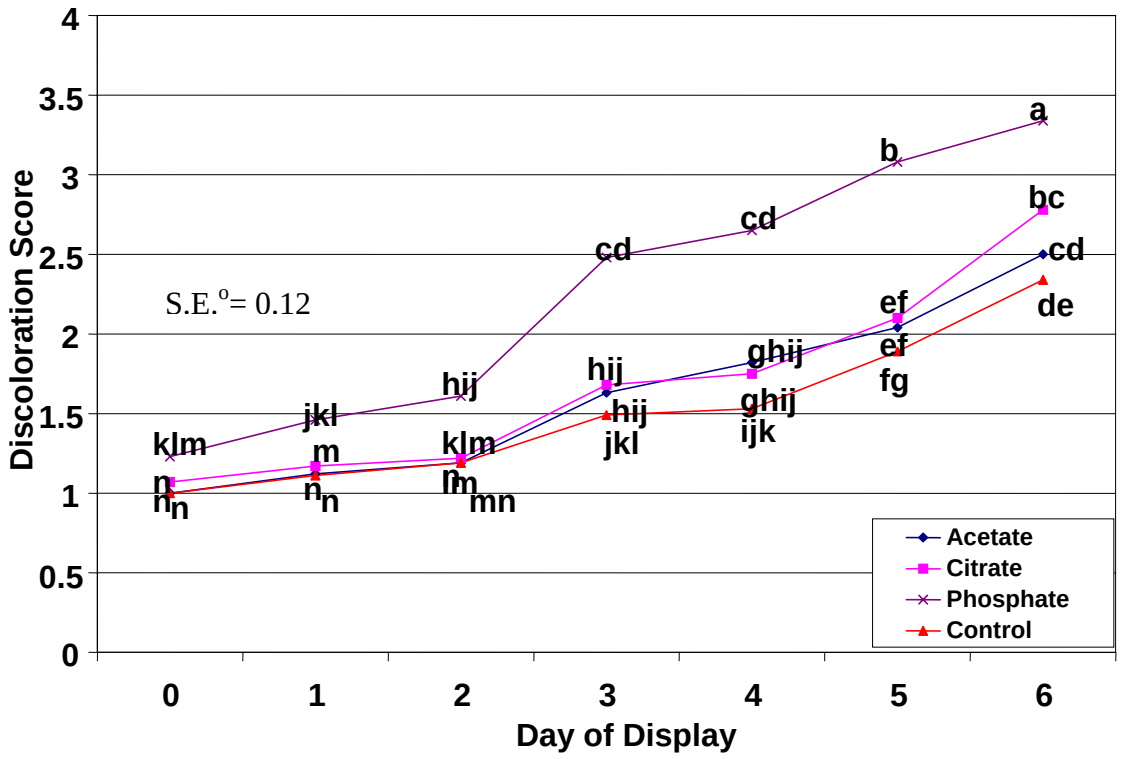
[abc]Main effect means lacking common superscript letters (in parenthesis) differ ($P<0.05$),
Standard error for ante-mortem treatment main effect = 0.30,
Standard error for time main effect = 0.26.

Figure 6. Mean Concentrations of Lactate in *Longissimus* Muscle at 50 min and 3 and 12 h Post-mortem from Carcasses Injected at 50 min Post-mortem with Acetate or Citrate, Non-injected Controls, and Carcasses Designated for Injection with Phosphate + Salt at 24 h.



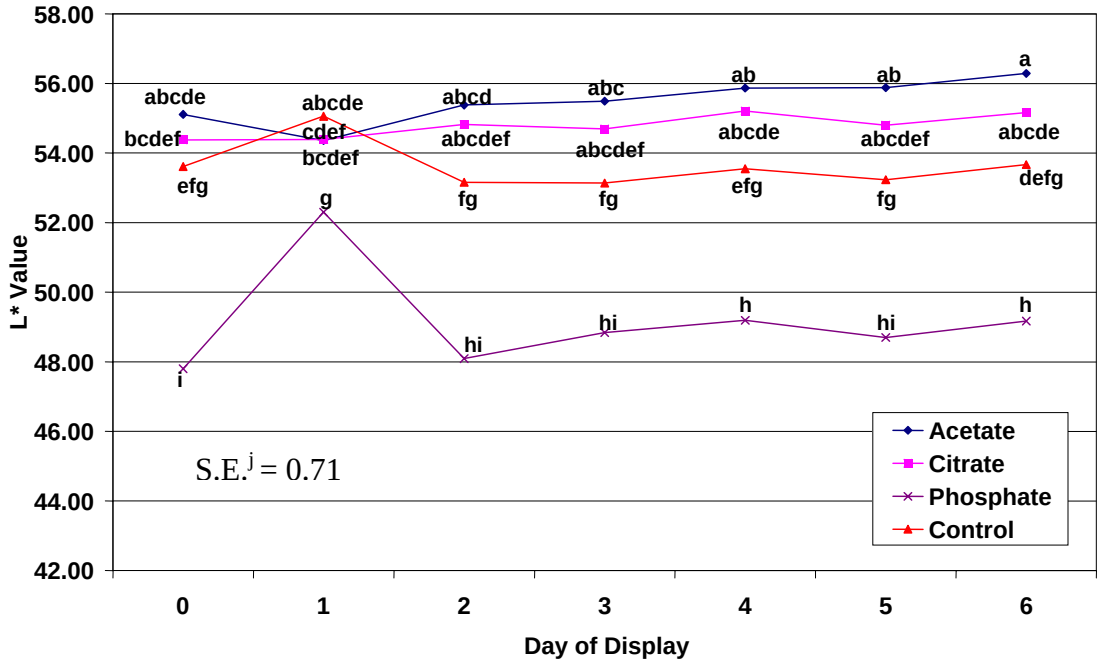
[a-q]Means lacking common superscript letters differ ($P<0.05$).
[r]Standard error of the interaction means.

Figure 7. Visual Color Scores for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



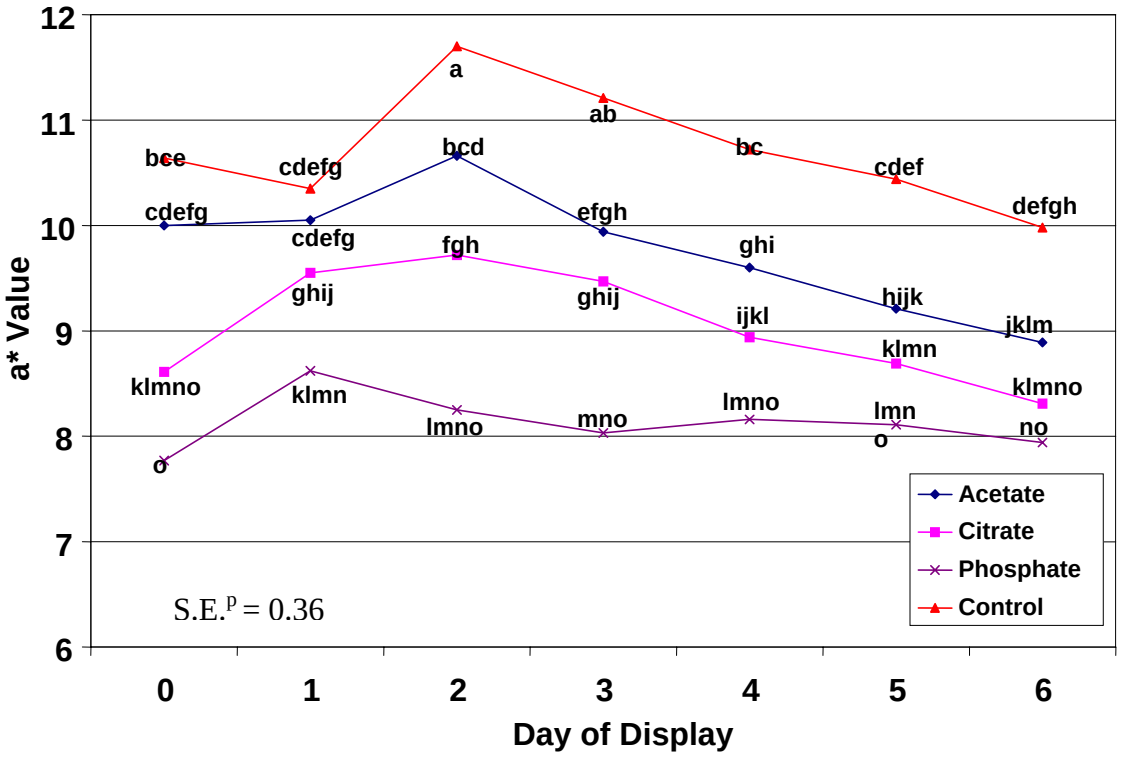
[a-n]Means lacking a common superscript letter differ ($P<0.05$).
[o]Standard error of the interaction means.

Figure 8. Discoloration Scores for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



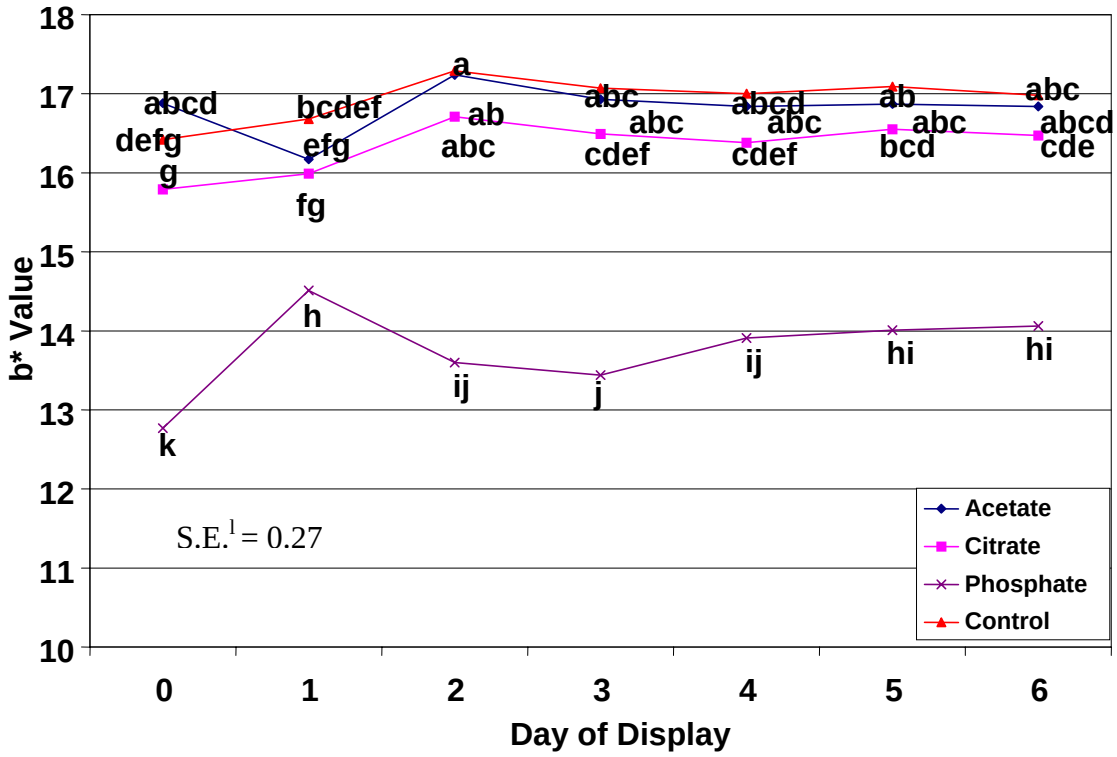
[a-i]Means lacking common a superscript letter differ ($P<0.05$).
[j]Standard error of the interaction means.

Figure 9. Values for L* for Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



[a-o]Means lacking common a superscript letter differ ($P<0.05$).
[p]Standard error of the interactions means.

Figure 10. Values for a* for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display.



[a-k]Means lacking common a superscript letter differ ($P<0.05$).
[l]Standard error of the interaction means.

Figure 11. Values for b* for *Longissimus* Chops from Acetate or Citrate Injection at 50 min Post-mortem, Phosphate plus Salt Injection at 24 h, and Non-injected Controls over 7 d of Display

INDEX OF KEY WORDS

ACKNOWLEDGMENTS

Appreciation is expressed to these organizations for assisting with swine research at Kansas State University.

ADM Animal Health and Nutrition, Des Moines, IA
Anjinomoto Heartland LLC, Chicago, IL
Chr. Hansen Biosystems, Milwaukee, WI
Eichman Farms, St. George, KS
Elanco, Indianapolis, IN
Exseed Genetics, LLC, Owensboro, KY
Hill's Pet Nutrition Inc., Topeka, KS
Independent Salt, Kanopolis, KS
Kansas Pork Association, Manhattan, KS
Kansas Swine Alliance, Abilene, KS
Keesecker Agri Business, Washington, KS
Kemin Industries, Des Moines, IA
Key Milling, Clay Center, KS
Kyodo Shiryo, Yokohama, Kanagawa, Japan
Livestock and Meat Industry Council, Manhattan, KS
Lonza, Inc., Fair Lawn, NJ
N & N Farms, St. George, KS
National Pork Board, Des Moines, IA
New Horizon Farms, Pipestone, MN
North Central Kansas Processors, Washington, KS
Novus International, St. Louis, MO
Phibro Animal Health, Fairfield, NJ
PIC USA, Franklin, KY
Pipestone System, Pipestone, MN
Purco, Pipestone, MN
Saf Agri, Minneapolis, MN
Soda Feed Ingredients, Dublin, Ireland
Steven Cox Associates, Long Island, KS
United Feeds, Sheridan, IN
Zenith Project, Geneseo, KS
Zephyr Project, Geneseo, KS

We especially appreciate the assistance and dedication of Crystal Groesbeck, Mark Nelson, Lyle Figgy, Eldo Heller, and Theresa Rathbun.

Swine Industry Day Committee

Jim Nelssen, Chairman

Duane Davis	Joel DeRouchey
Steve Dritz	Mike Tokach
Bob Goodband	Joe Hancock

Contribution No. 06-63-S from the Kansas Agricultural Experiment Station.

The Livestock and Meat Industry Council, Inc.

The Livestock and Meat Industry Council, Inc. (LMIC) is a non-profit charitable organization supporting animal agriculture research, teaching, and education. This is accomplished through the support of individuals and businesses that make LMIC a part of their charitable giving.

Tax-deductible contributions can be made through gifts of cash, appreciated securities, real estate, life insurance, charitable remainder trusts, bequests, as well as many other forms of planned giving. LMIC can also receive gifts of livestock, machinery, or equipment. These types of gifts, known as gifts-in-kind, allow the donor to be eligible for a tax benefit based on the appraised value of the gift.

Since its inception in 1970, LMIC has provided student scholarships, research assistance, capital improvements, land, buildings, and equipment to support students, faculty, and the industry of animal agriculture. If you would like to be a part of this mission or would like additional information, please contact the Livestock and Meat Industry Council/Animal Sciences and Industry, Weber Hall, Manhattan, Kansas 66506 or call 785-532-1244.

LMIC Board Members:

Max Deets	Dell Allen	Andrew Murphy
Kenny Knight	Raymond Adams, Jr.	Tom Perrier
Henry Gardiner	Gina Miller	Duane Walker
Sam Hands	Phil Phar	Pat Koons
Lyle Gray	Mikel Stout	Lee Reeve
Bernie Hansen	Jerry Bohn	Randy Fisher
Larry Jones	Steve Hunt	Craig Good
Jan Lyons	Steve Irsik, Jr.	Greg Henderson
Galen Fink	Ken Stielow	Warren Weibert

Royal Board Members:

Bill Amstein	Richard Chase	Stan Fansher
Calvin Drake	Don Good	Harland Priddle
Don Smith	Fred Germann	

Auxiliary Board Members:

Fred Cholick	Janice Swanson

SWINE RESEARCH 2005

This publication is produced by the Department of Communications at Kansas State University and is intended for distribution at Swine Industry Day. The full publication is available on CD or via the World Wide Web at:

http://www.oznet.ksu.edu/library [type Swine Research in the search box].

Printed versions of the publication are available upon request.

Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan 66506

SRP 964 November 2005