1999

1999 Nebraska Swine Report

Duane E. Reese

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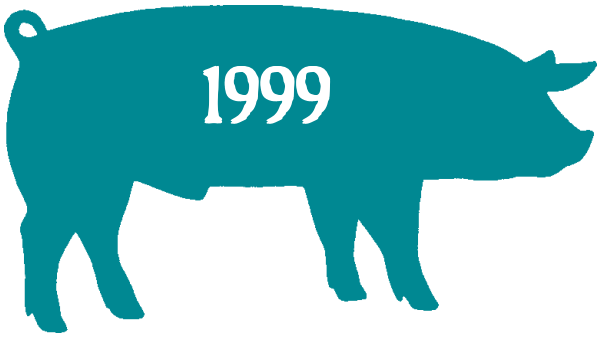

NEBRASKA SWINE REPORT

- Reproduction
- Genetics
- Health
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- Housing

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Prepared by the staff in Animal Science and cooperating Departments for use in Extension, Teaching and Research programs.

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University of Nebraska-Lincoln

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Swine Report Acknowledgments for 1999

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The 1999 Nebraska Swine Report was compiled by Duane E. Reese, Associate Professor and Extension Swine Specialist, Animal Science, Department of Animal Science.

Cover Art Caption:

Meat consistency, meat quality, and food safety are major issues facing the pork industry. Research, teaching and extension programs at the University of Nebraska are being directed at these issues.

1999
Nebraska Swine Report

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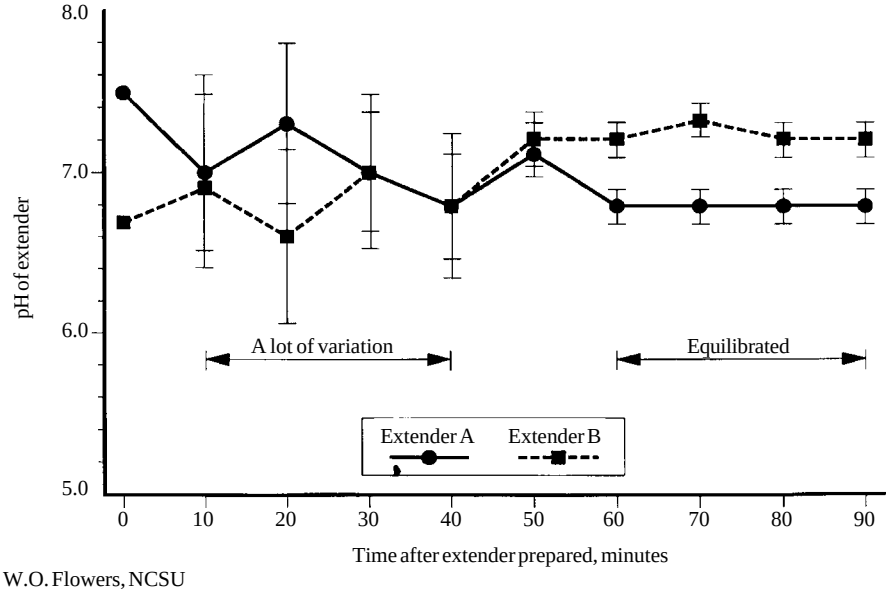
Changes in pH of Boar Semen Extenders

Mary Sue Newth
Donald G. Levis[1]

Summary and Implications

An experiment was conducted to examine the change in pH across time of five extenders (MR-A, VSP, BTS, Merck III and SpermAid). Type of extender and time of measurement affected (P < .01) the overall pH of liquid extender; however an interaction (P < .01) occurred between type of extender and time. BTS and MERCK III had a small increase in pH across time, MR-A and VSP had a linear increase in pH across time and SpermAid decreased in pH during the first 20 minutes before gradually increasing to a consistent level of pH at 50 minutes after preparation. Boar semen extenders do not have the same pattern of pH change across time. Semen should not be mixed with extender until a stable pH has been reached. In general, a liquid boar semen extender should be prepared 60 to 90 minutes prior to mixing with raw semen.



W.O. Flowers, NCSU

Figure 1. Changes in pH of two semen extenders during the first 90 minutes after preparation.

Introduction

Although artificial insemination application has rapidly increased in the last five years, numerous semen processing and storage procedures need additional research. For example, research at North Carolina State University indicates the pH of two boar semen extenders (identity of extenders was not given) require at least 60 minutes for the pH to equilibrate after distilled water was added to the powder (Figure 1). If spermatozoa are to be provided a "stable" environment of

(Continued on next page)

pH at the time of diluting, an extender should be prepared at least one hour prior to use. The objective of this experiment was to determine whether pH within an individual packet of semen extender varies across time for five different extenders.

Materials and Methods

The five extenders examined were MR-A, VSP, Beltsville Thawing Solution (BTS), SpermAid and Merck III. The total weight of the powder in an individual packet was divided into four equal portions. Each portion of powder was placed in a separate 500 mL beaker and 250 mL of warm (≈95 degrees F) distilled water was added. The pH of the liquid extender was taken immediately after mixing and every 10 minutes thereafter until 90 minutes had elapsed. All beakers were placed on a cardboard box (1" L x 10" W x 2" H) and kept at room temperature. One packet of each extender was used and data were analyzed for time effects by using analysis of variance for repeated measures.

Results and Discussion

The type of extender (Figure 2) and time at measurement (Figure 3) affected ($P < .01$) the overall average pH of liquid extender. However, an interaction ($P < .01$) occurred between type of extender and time of measurement. Two extenders had a small average increase in pH across time (Merck III 6.92 $\pm$ .04 to 6.97 $\pm$ .01; BTS, 7.07 $\pm$ .01 to 7.15 $\pm$ .01), two extenders had a linear increase in pH across time (MR-A 6.81 $\pm$ .03 to 6.99 $\pm$ .02; VSP, 6.70 $\pm$ .08 to 7.05 $\pm$ .07) and one extender (SpermAid) had a decrease in pH during the first 20 minutes before gradually increasing to a consistent pH at 50 minutes after preparation (Figure 4).

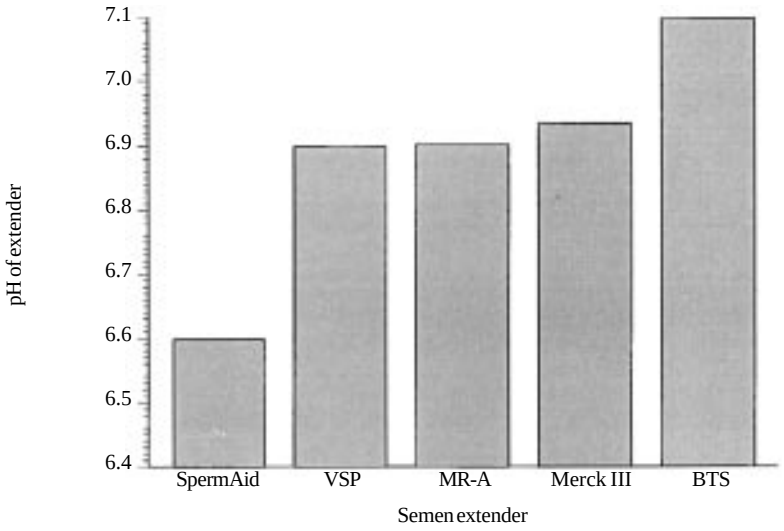


Figure 2. Overall average pH of five semen extenders.

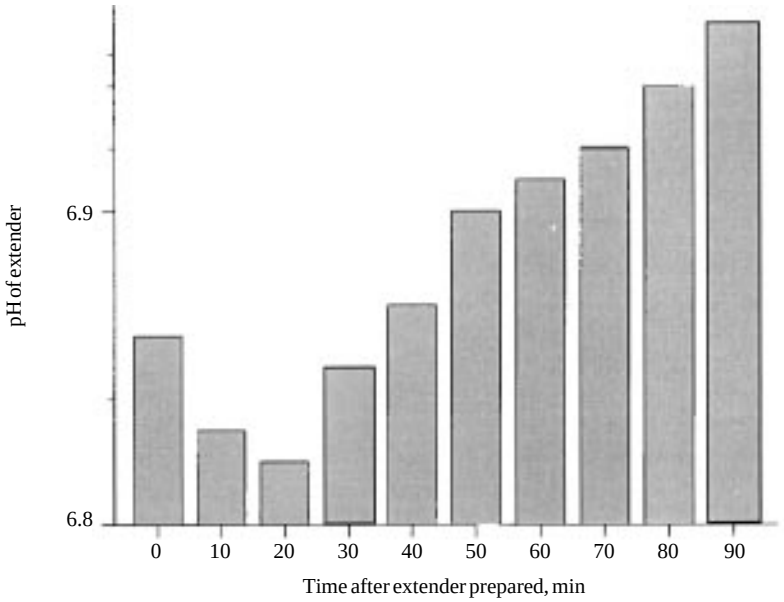


Figure 3. The main affect of time on average pH of semen extenders.

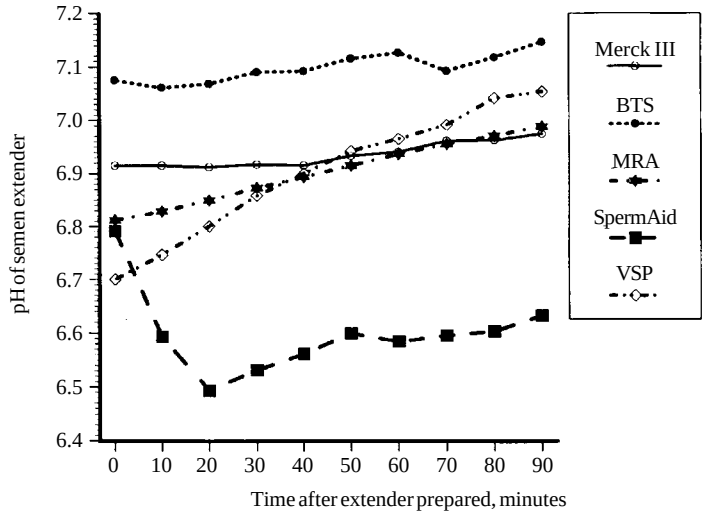


Figure 4. The interaction of time after extender prepared by type of semen extender.

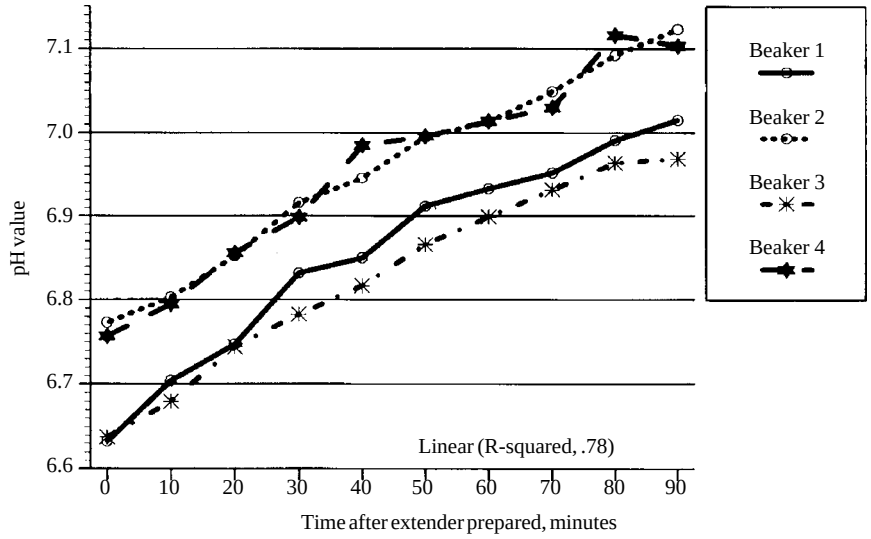


Figure 5. Pattern of change in pH over time for VSP semen extender.

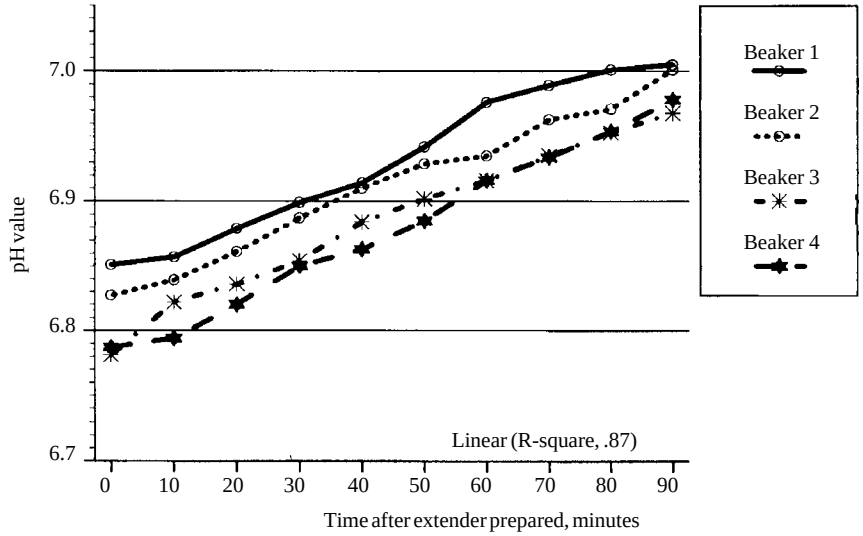


Figure 6. Pattern of change in pH over time for MR-A semen extender.

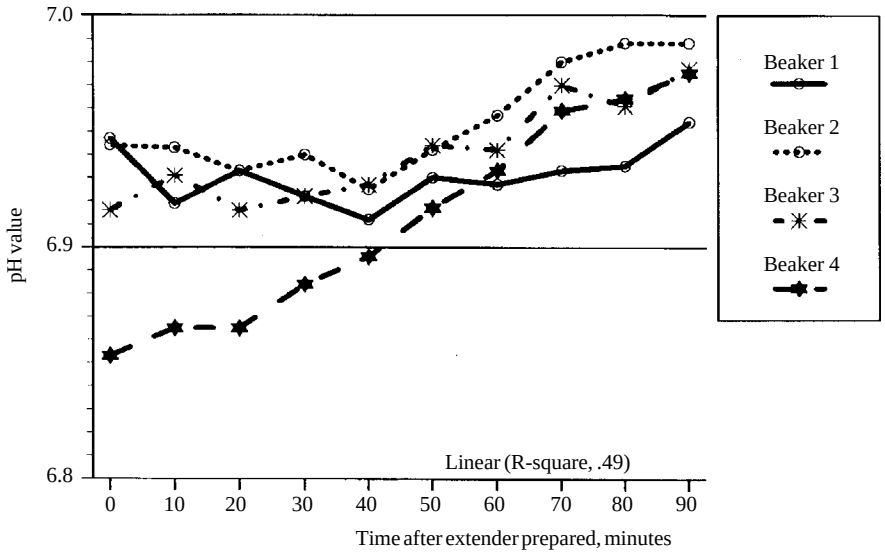


Figure 7. Pattern of change in pH over time for Merck III semen extender.

The pattern of change in pH among the four beakers within an extender is shown in Figures 5 through 9. These data suggest boar semen extenders do not uniformly change in pH across time. Although only one packet of extender was used for each type of extender, it is likely all packets of the same extender have the same pattern of pH change. Research needs to be conducted to determine whether boar spermatozoa are damaged when diluted with an extender of unstable pH.

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[1]Mary Sue Newth was a recipient of a Howard Hughes Medical Institute grant for undergraduate research experience in biological sciences. Donald G. Levis is a professor and extension swine specialist, Department of Animal Science.

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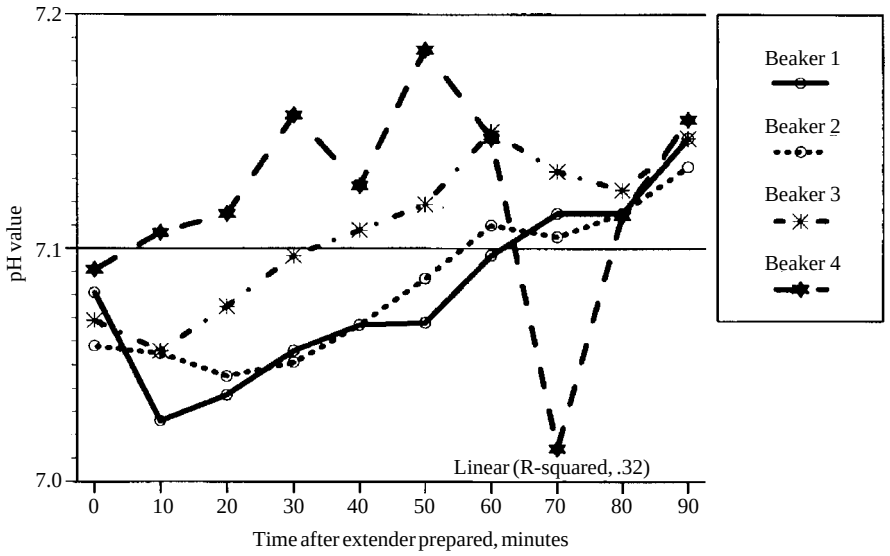

Figure 8. Pattern of change in pH over time for BTS semen extender.

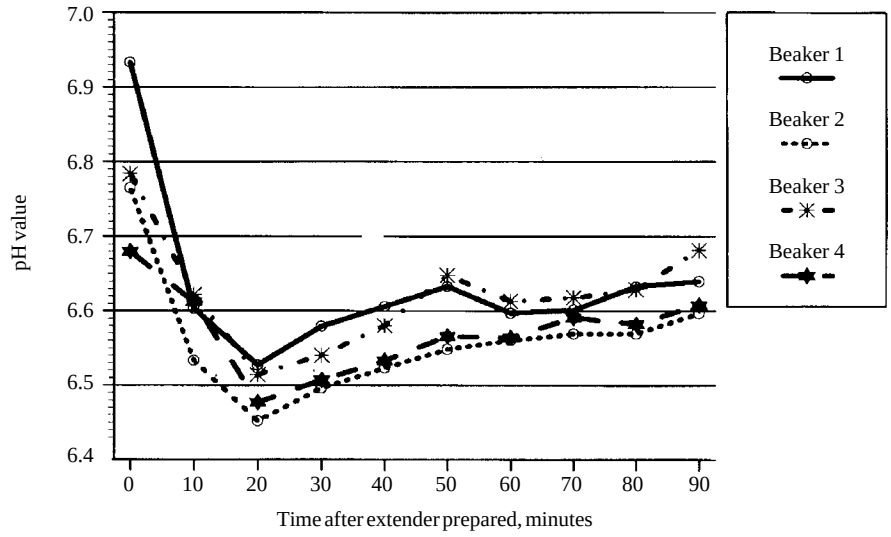

Figure 9. Pattern of change in pH over time for SpermAid semen extender.

Follicular Selection and Atresia in Gilts Selected for an Index of High Ovulation Rate and High Prenatal Survival

Hui-Wen Yen
Rodger K. Johnson
Dwane R. Zimmerman[1]

Summary and Implications

Previously, we reported (See Yen et al., Nebraska Swine Report 1998) White Line gilts selected for an index of high ovulation rate and high prenatal survival (White Line-2, WL-2) maintained a larger pool of medium follicles (3 to 6.9 mm) during the early- to mid-follicular phase than randomly selected controls (White Line-1, WL-1). The present study evaluated the health status of the medium follicles to determine whether WL-2 gilts maintain a healthier pool of medium follicles and are able to continue selection of ovulatory follicles later in the follicular phase to achieve their ovulation rate advantage (6.6 ova). Ovaries were recovered on days zero, two three, four and five after induced luteolysis with PGF2α on day 13 (day zero) of the estrous cycle. Numbers of follicles (F) equal or greater than 3 mm in diameter were categorized by size and recorded as follows: medium-1 (M1F, 3 to 4.9 mm), medium-2 (M2F, 5 to 6.9 mm) and

large (LF ≥ 7 mm). Estradiol (E) concentration in follicular fluid was used to classic individual M2F and LF as healthy (≥ 100 ngE/mL) or atretic (< 100 ngE/mL). M1F were not estrogen-active (<60 ngE/mL) and could not be evaluated for atresia with this method. Mean E concentrations in M2F increased linearly from day two to day five in WL-2 gilts while E concentrations increased rapidly between day two and day three and then plateaued in WL-1 gilts. All LF were estrogen active (≥ 100 ngE/mL) and classified as healthy in both genetic lines. The percentage of healthy M2F increased rapidly in WL-2 gilts between day three and day five whereas percent of healthy M2F remained unchanged in WL-1 gilts during this period. Mean numbers of healthy M2F increased rapidly in WL-2 gilts between day two and day four and then declined to day five. Numbers of healthy M2F in WL-1 gilts increased between day two and day three and then declined to day four and day five. The greatest difference occurred on day four. WL-2 gilts maintain a larger pool of healthy M2F to day four of the follicular phase and rapidly select and mature these follicles into ovulatory follicles to achieve their ovulation rate advantage. Both genetic lines need to select about six additional ovulatory follicles from the M2F pool after day five to achieve final ovulation rates. Greater understanding of the biological basis of the improvement in follicular dynamics in the WL-2 population may prove useful in developing more efficient methods for improving ovulation rate and enhancing litter size in swine.

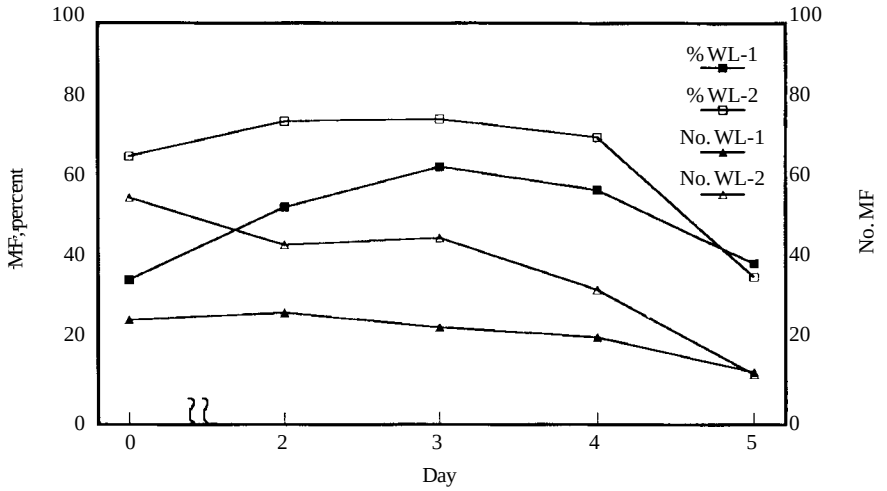

Figure 1. Mean numbers and relative percentage of medium follicles (3 to 6.9 mm) following PGF2-alpha on day 13 (day 0) of the estrous cycle.

Introduction

Increasing litter size can improve efficiency of swine production. Variation in litter size is determined by the number of follicles that ovulate and release viable ova, the percentage of ova fertilized by sperm and the percentage of beginning embryos and fetuses that survive in utero during gestation and are born alive.

Selection for high ovulation rate in the University of Nebraska gene pool population increased ovulation rate by about 3.2 ova over randomly selected control line gilts, but the number of pigs born alive increased less than one pig per litter after nine generations of selection. The limited litter size response led to the design of a second selection experiment where selection was based on both an index of the ability of females to maintain large litters to day 50 of gestation (percent prenatal survival) and ovulation rate (see Johnson, Nebraska Swine Report 1990). This experiment utilized a Large White x Landrace composite population and has proved more effective at increasing both ovulation rate and litter size. The ovulation rate and litter size advantages for the index selected line over the randomly selected control line averaged 6.7 ova and 1.5 pigs after 10 generations of selection (see Johnson, Nebraska Swine Report 1998).

The pathway to expressing high or low ovulation rate may reflect differences in the numbers of follicles recruited and maintained during the luteal phase and, in turn, the size and health status of the pool of medium follicles available for selection and maturation into large ovulatory follicles during the follicular phase.

Our laboratory reported previously that WL-2 gilts maintain a larger pool of medium follicles (3 to 6.9 mm) than WL-1 gilts during the early- to mid-follicular phase of the estrous cycle (Figure 1) and rapidly mature the larger M2 (5 to 6.9 mm) follicles into large ovulatory follicles (≥ 7 mm) between day four and day five of the follicular phase (Figures 2 and 3). We hypothesized the pool of medium follicles maintained by WL-2 gilts during the follicular phase is not only larger but also healthier and that the ovulation rate advantage is achieved by continued selection of ovulatory follicles from the medium follicle pool during the mid- to late-follicular phase. The objective of the present study was to determine differences in the health status of medium follicles during the follicular phase in gilts selected for an index of high ovulation rate and prenatal survival (WL-2) versus randomly selected control line gilts (WL-1).

Materials and Methods

Fifty-nine tenth generation WL-1 and WL-2 gilts were assigned randomly within sire for ovary recovery on days zero, two, three, four and five after induced luteolysis (regression of corpora lutea) with PGF2α (10 mg Lutalyse) on day 13 (day zero) of the estrous cycle. Gilts from WL-1 and WL-2 represented the progeny of 11 and nine sires, respectively. These gilts were 8 to 11 months of age and weighed between 209 and 330 pounds when evaluated. They had experienced two

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or more estrous periods before assignment. Distribution of gilts by line and day of evaluation were: day zero (n=7 WL-1 and 5 WL-2), day two (n=7 WL-1 and 6 WL-2), day three (n=5 WL-1 and 6 WL-2), day four (n=5 WL-1 and 6 WL-2) and day five (n=7 WL-1 and 5 WL-2).

Ovaries were recovered at slaughter and placed in .9 percent saline on ice. The numbers of corpora ablicantia (CA) were recorded as a measure of ovulation rate at the previous estrus. Numbers of follicles (F) equal or greater than 3 mm in diameter were categorized by size and recorded as follows: medium-1 (M1F, 3 to 4.9 mm), medium-2 (M2F, 5 to 6.9 mm) and large (LF, ≥ 7 mm). Estradiol (E) concentration in follicular fluid was used to classify individual M2F and LF as healthy (≥ 100 ngE/mL) or atretic (< 100 ngE/mL). M1F were not yet estrogen-active (< 60 ngE/mL) and could not be evaluated for atresia with this method. Mean concentrations of E in follicular fluid, percentage of healthy M2F and mean number of healthy M2F were analyzed statistically by the GLM procedure of SAS with line and day as main effects.

Result and Discussion

Overall, WL-2 gilts ovulated 6.6 more follicles than WL-1 gilts at the pretreatment estrus (20.4 versus 13.8, P<.01). This difference is similar to the line difference reported earlier (See Johnson, 1998 Nebraska Swine Report).

Concentrations of estradiol (E) in follicular fluid of M1F were low (< 60 ng/mL) throughout the follicular phase in both genetic lines. Mean E concentrations in M2F more than doubled between days two and three (108.7 versus 223.1 ng/mL) and then plateaued to day five in WL-1 gilts (Figure 4). In contrast, E increased rapidly in WL-2 gilts between day three and day four (150.9 versus 275.9 ng/mL) and had increased to a substantially higher level on day five (352.6 ng/mL, P<.01) than in WL-1 gilts (Figure 4). These data suggest the M2F population of WL-1 and WL-2 gilts

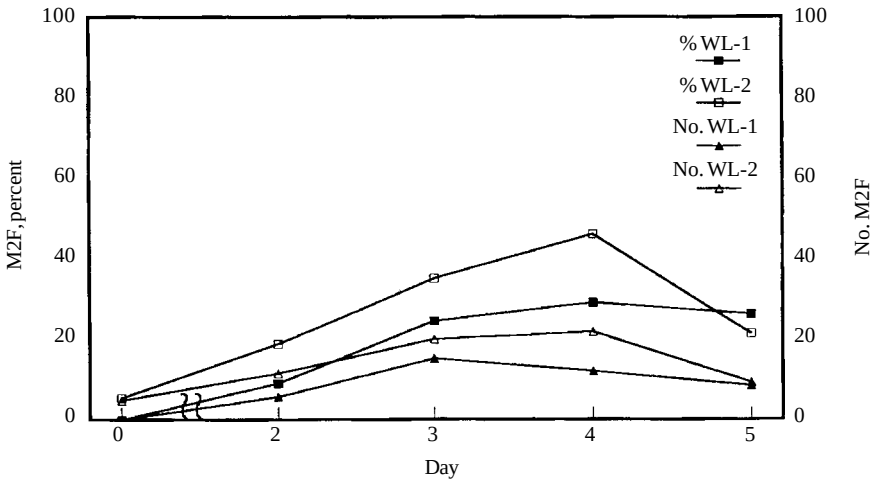

Figure 2. Mean numbers and relative percentage of medium-2 follicles (5 to 6.9 mm) following PGF2-alpha on day 13 (day 0) of the estrous cycle.

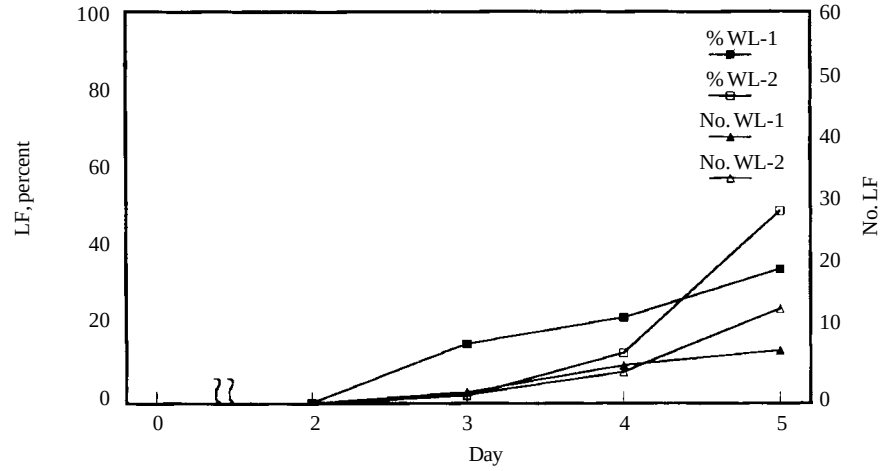

Figure 3. Mean numbers and relative percentage of large follicles (≥ 7 mm) following PGF2-alpha on day 13 (day 0) of the estrous cycle.

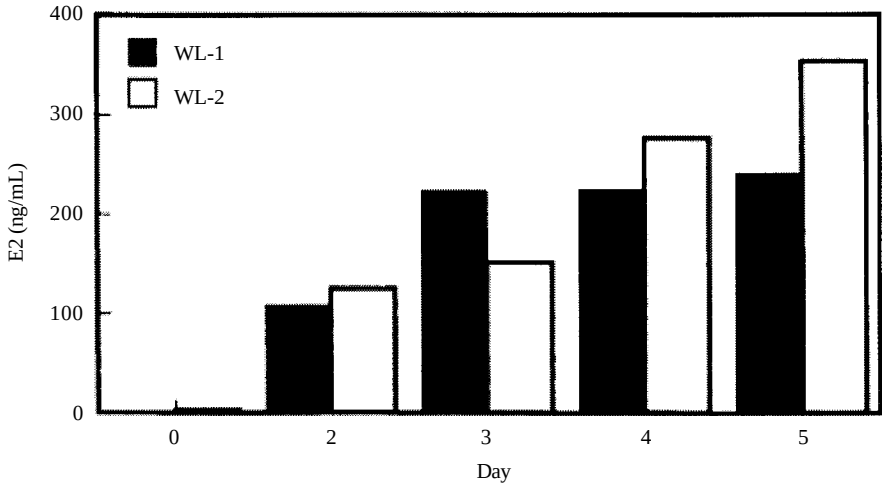

Figure 4. Mean concentrations of estradiol (E2) in follicular fluid from individual M2 (5 to 6.9 mm) follicles following PGF2-alpha on day 13 (day 0) of the estrous cycle.

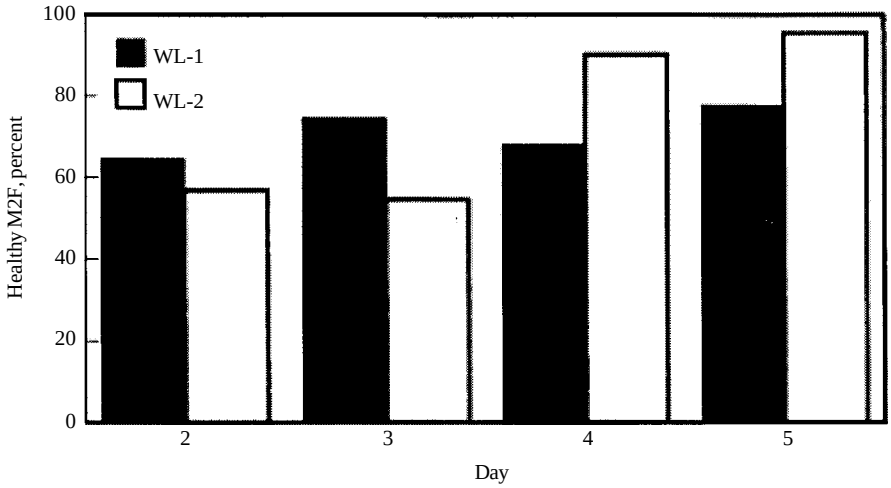

Figure 5. Percentage of healthy M2 (5 to 6.9 mm) follicles following PGF2-alpha on day 13 (day 0) of the estrous cycle.

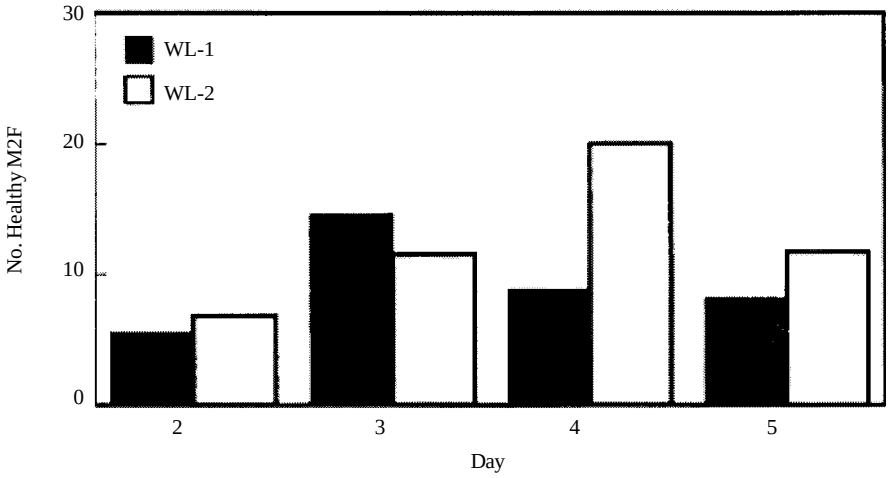

Figure 6. Mean numbers of healthy M2F (5 to 6.9 mm) following PGF2-alpha on day 13 (day 0) of the estrous cycle.

are in different functional states during the follicular phase. M2 follicles in WL-1 show a major increase in functional activity between days two and three but do not continue to increase after day three, whereas WL-2 gilts sustain increased functional activity after day three of the follicular phase. The M2F population of WL-2 gilts is probably more mature, and perhaps healthier, later in the follicular phase than the M2F pool of WL-1 gilts.

Medium follicles would have to be healthy to be selected and develop into large ovulatory follicles. Therefore, the health status of individual M2F was evaluated and compared between lines. Percentages of healthy M2F were greater numerically, but not statistically, in WL-1 gilts on days two and three (WL-1, 64.6 and 74.6 percent versus WL-2, 56.8 and 54.6 percent, P>.1; Figure 5). Percentages of healthy M2F increased rapidly in WL-2 from days three to five (54.6 versus 95.5 percent, P<.07) whereas percentage of healthy M2F remained unchanged in WL-1 gilts from days three to five (74.5 versus 77.8 percent, Figure 5). Mean numbers of healthy M2F increased about 2.6 fold (5.5 versus 14.6, P<.06) in WL- 1 gilts between day two and day three and then declined to day five (Figure 6). In contrast, mean numbers of healthy M2F in WL-2 gilts increased linearly from 6.8 to 20 between day two and day four and then declined to day five (Figure 6). These results suggest that WL-2 gilts were able to maintain a larger pool of healthy M2F during the mid- to late-follicular phase and mature these healthy M2F rapidly into LF after day four to achieve their ovulation rate advantage.

Table 1. Line differences in number of corpora albicantia (CA), healthy medium and large follicles on day five after PGF2-alpha on day 13 (day 0).

	Follicle Size[a]		
Line	M2	L	No. CA[b]
WL-1	8.1	8.1[c]	13.8[c]
WL-2	11.6	14.5	20.4

[a]M2, 5 to 6.9 mm; L, 7 mm and above.
[b]Ovulation rate at pretreatment estrus.
[c]P<.01.

All LF were estrogen active (≥ 100 ngE/mL) and classified as healthy in both genetic lines. The number of LF observed on day five differed between the two genetic lines (WL-1, 8.1 versus WL-2, 14.5, P<.01) but did not reflect the expected ovulation rate of either line (Table 1). Both lines must continue selecting ovulatory follicles from the healthy pool of M2F in order to achieve their final ovulation rate. To achieve ovulation rates comparable to that expressed at the previous estrus, each line would have to mature about six M2F into large ovulatory follicles before time of ovulation.

Conclusion

Follicular dynamics have been changed in response to genetic selection for high ovulation rate and high prenatal survival. Selected WL-2 gilts develop M2F earlier in the follicular phase and achieve a larger pool of healthy M2F from which they select LF later into the follicular phase. After day four, WL-2 gilts rapidly select and mature their healthy M2F into LF to achieve their ovulation rate advantage.

[1]Hui-Wen Yen is a graduate student and Rodger K. Johnson and Dwane R. Zimmerman are professors in the Department of Animal Science.

A Population Approach to Diagnosis of Grow-Finish Diarrhea Complex

Gerald E. Duhamel
Michelle R. Mathiesen[1]

Summary and Implications

Because the growing-finishing phase of pig production accounts for 60 to 70 percent of the total feed costs, improvements in feed efficiency during that period can significantly effect cost-benefit potential. Alimentary tract diseases caused by bacterial agents can significantly impact the capacity of growing-finishing pigs to utilize nutrients. Although disease problems in the poultry industry are most often diagnosed by complete examination of several live animals submitted for necropsy, such an approach is cost prohibitive for growing-finishing pigs. To better control enteric bacterial diseases of growing/finishing pigs, we investigated the value of examining fecal specimens taken front a representative number of potentially exposed or infected pigs for the presence of three major enteric bacterial pathogens. We hypothesized that examining such fecal specimens would provide useful information about a farm's bacterial enteric infection status. These results indicated cost-effective control strategies aimed at enteric bacterial diseases on individual farms should be implemented. This approach also could form the basis of a surveillance program for control of bacterial agents with a public health significance.

Introduction

Although viruses are common in most body systems, diseases of the alimentary tract of growing-finishing pigs are almost exclusively caused by bacterial infections. The major known bacterial diseases affecting the alimentary tract of pigs at this stage include proliferative enteritis or "ileitis" caused by *Lawsonia intracellularis*, salmonellosis caused by *Salmonella typhimurium/agona/derby*, colonic spirochetal infections caused by *Serpulina hyodysenteriae* (swine dysentery) and *Serpulina pilosicoli*, the cause of porcine colonic spirochetosis.

Infection frequency within an animal population can be viewed as having a normal distribution with a proportion of uninfected healthy animals at one end of the spectrum and severely infected animals in the terminal stage of the disease at the other end (Figure 1). Between these two extremes sits a population of animals either exposed or infected with the agent, but may or may not show signs of disease. Traditionally, laboratory diagnosis of alimentary tract diseases of growing-finishing pigs has meant complete examination of a few severely affected or dead animals. Although this approach is highly specific and allows all possible concurrent disease problems to be identified, it is relatively insensitive because only a few animals are examined and the findings may not represent the disease affecting the at-risk population.

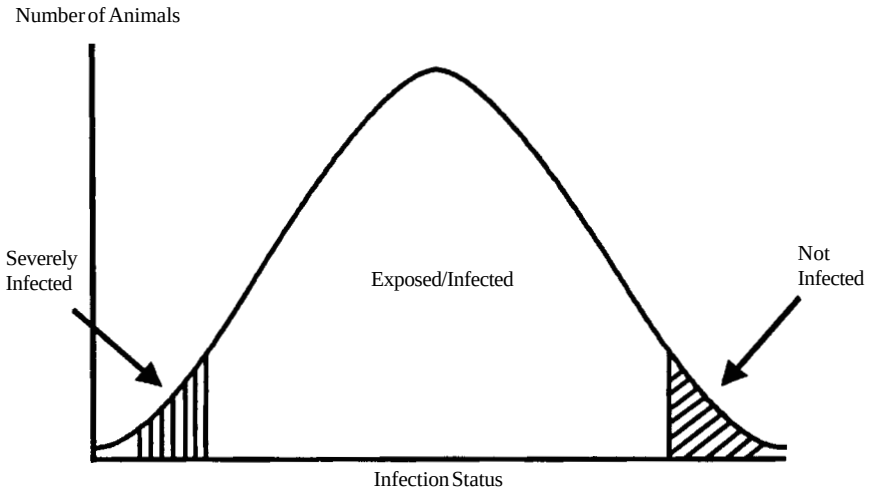

Figure 1. Normal distribution of infection frequency in a population of susceptible animals.

Table 1. Number of fecal specimens positive for the presence of bacterial agents potentially involved in diarrheal disease of growing-finishing pigs.

Farm	No. specimens examined	*Lawsonia intracellularis* (%)	Salmonellae‡ (%)	Spirochetes† WBHIS (%)	*S. pilosicoli* (%)
IA1	17	3 (17.6)	0	0	NA
ID1	15	6 (40.0)	2 (13.3)	0	NA
KS1	21	3 (14.3)	2 (9.5)	0	NA
SC1	22	1 (4.5)	2 (9.1)	2 (9.1)	2/2
OH1	18	11 (61.1)	1 (5.6)	4 (22.2)	0/4
SD1	10	3 (30.0)	0	2 (20.0)	0/2
OH2A	10	0	5 (50.0)	0	NA
OH2B	11	0	10 (90.9)	0	NA
OH2C	11	0	11 (100.0)	0	NA
OH2D	10	0	6 (60.0)	1 (10.0)	0/1
1A2	10	0	7 (70.0)	2 (20.0)	0/2
SC2	40	0	1 (2.5)	13 (32.5)	0/11
IL1	20	0	0	0	NA
SD2	9	0	0	0	NA

‡ID1, serotype unidentified; KS1, *S. agona*; SC1, *S. brandenburg*; OH1 *S. orion*; OH2, *S. typhimurium* var. *copenhagen*; IA2, serotype unidentified; SC2, *S. typhimurium* var. *copenhagen*.
†WBHIS = weakly β-hemolytic intestinal spirochetes; *S. pilosicoli*, number positive/number tested; NA = Not applicable.

Assuming an intervention strategy is available to control the infecting agent, it would be desirable to determine the infection status of the population with the highest potential benefit for treatment. To improve our ability to control enteric bacterial diseases, we investigated the value of examining fecal specimens taken from a representative number of potentially exposed or infected animals for the presence of three major enteric bacterial pathogens. We hypothesized examining fecal specimens taken from animals with clinical signs of diarrhea would provide useful information about the bacterial enteric infection status of a farm.

Materials and Methods

Between April and August 1998, 224 fecal specimens (nine to 40 per farm) were obtained from growing-finishing pigs on 14 farms with a history of diarrhea. Swabs obtained directly from the rectum of pigs with diarrhea or from fresh, undisturbed loose stools on the floor were placed in Amies transport medium with charcoal and shipped on ice by overnight courier for laboratory examination. Each specimen was processed immediately upon arrival according to a protocol for bacteriologic examination developed in our laboratory.

Results

The results of laboratory examinations are presented in Table 1. As expected, prevalence of each agent varied by farm. Mixed infections were present on four farms (ID1, KS1, SC1, OH1) and two farms had no bacterial agents identified (IL1 and SD2). *Lawsonia intracellularis* was identified on six farms; two without other significant bacterial agents (IA1 and SD1); three with Salmonellae; one with *Salmonella brandenburg* and *Serpulina pilosicoli* (SC1). Four finisher farms in Ohio had a high prevalence of *Salmonella typhimurium* var. *copenhagen* and also shared a common feed supplier and feeder pig source. Farm IA2 had a high prevalence of an unidentified Salmonellae. *Salmonella typhimurium* var. *copenhagen* was isolated from one specimen from farm SC2, but spirochetes that were different from *Serpulina pilosicoli* were isolated from 13/40 (32.5 percent) of the samples. None of the specimens yielded *Serpulina hyodysenteriae*.

Discussion

A population approach to diagnosing three major enteric bacterial diseases indicated considerable variation among farms with a history of diarrhea among growing-finishing pigs. For example, a complex of more than one bacterial agent was identified on four farms. This is likely to occur when pigs from different sources with different health and immune status, genetic background and endogenous gut flora mingle. However, at the time of sampling, one bacterial agent appeared to predominate over the others on farm ID1 and farm OH1, whereas similar prevalence of either *Lawsonia intracellularis* and *Salmonella agona* and *Lawsonia intracellularis, Salmonella brandenberg* and *Serpulina pilosicoli* were present on farm KS1 and farm SC1, respectively.

Although several farms were included in this pilot study, statistical inferences about specific bacterial agent prevalence rates could not be made. Nevertheless, about half of the farms examined had between 4.5 percent and 61.1 percent of the specimens positive for the presence of *Lawsonia intracellularis*, suggesting a high prevalence of this agent in diarrheal samples taken from growing-finishing pigs. Four finisher farms in Ohio had a high prevalence of *Salmonella typhimurium* var. *copenhagen*. These farms shared a common feed supplier and source of feeder pigs and therefore cannot be considered independent farms. By contrast, farm SC2 had only 2.5 percent of 40 specimens positive for *Salmonella typhimurium* var. *copenhagen*, making interpretation of this finding in relation to the diarrheal problem on this farm more difficult. However, one-third of the specimens collected on farm SC2 also had spirochetes different from *Serpulina pilosicoli*. The high prevalence of spirochete shedding suggested a

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potential role for this organism in the disease problem on this farm. Final identification of the spirochete might reconcile the laboratory results with the clinical problem.

The results of the laboratory examinations are affected by the relative sensitivity of the various methods, the length of fecal shedding of each agent and the rate of new infections within the population. Therefore, the most commonly isolated agent might not be the one that causes the most disease. Additionally, demonstration of a bacterial agent in a fecal specimen might not be sufficient to establish a cause and effect relationship; infection might not always equal disease. In spite of these limitations, diagnosis of enteric bacterial infections in live animals can provide a basis for implementing strategic interventions to address problems in order of importance to the population at risk.

Because transmission of enteric bacterial disease agents occurs primarily through the fecal-oral route, control measures aimed at reducing environmental contamination, including sanitation and antimicrobial therapy, are most critical. By focusing diagnostic efforts on the population with the highest benefit potential for treatment, it is possible to maximize the return on diagnostic investment. However, mixed infections are expected to cause more severe disease problems and have prolonged recovery with more variable response to therapy than single infections.

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Survival of Pathogenic Intestinal Spirochetes Kept in Pure Cultures and in Pig Feces Held at Four Different Temperatures

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Michelle R. Mathiesen[1]

Summary and Implications

Porcine colonic spirochetosis (PCS) caused by Serpulina pilosicoli has been identified as a contributing cause of diarrhea and reduced performance of growing pigs in all major swine producing countries. The current view that transmission of PCS occurs through contamination of the environment by acutely or persistently infected pigs is based on the assumption that the spirochetes remain viable in the environment. The purpose of this study was to compare the viability of Serpulina pilosicoli kept in pure culture or mixed with feces at four different temperatures over time with that of Serpulina hyodysenteriae. The results of the present study indicated Serpulina pilosicoli survived considerably longer than Serpulina hyodysenteriae in pure cultures held at 75°F and 99°F, and at all temperatures in spiked fecal materials. Pure cultures of Serpulina pilosicoli survived for at least 63 days at -158°F, seven to 14 days at 39°F 14 to 28 days at 75°F and seven to 28 days at 99°F. The survival of each spirochete mixed with feces was similar as pure cultures for samples kept at -158°F and 39°F but was reduced to one to seven days at 75°F and one to three days at 99°F for Serpulina pilosicoli and <five days at 75°F and < one day at 99°F for Serpulina hyodysenteriae. Information on the survival of Serpulina pilosicoli outside the pig's body provides a basis to improve strategies for PCS control.

Introduction

Recent advances in genetic-based identification have led to the recognition of *Serpulina pilosicoli,* a new pathogenic intestinal spirochete difference from *Serpulina hyodysenteriae,* the cause of swine dysentery. First identified in 1980 in the United Kingdom, *Serpulina pilosicoli* was recognized as the etiologic agent of porcine colonic spirochetosis (PCS) in 1996. Since then, PCS has been identified as a contributing cause of diarrhea and reduced performance of growing pigs in North America, Europe and Australia.

The clinical signs of PCS consist of transient diarrhea, which is gray to green in color and the consistency of wet cement. Persistent infections cause a lack of uniformity in weight gain, increased days to market and increased feed costs. The disruption of pig flow and increased number of pigs with lighter weights at the end of the feeding period are major problems in all-in/all-out management systems.

Although the significance of PCS as a disease of growing-finishing pigs is well documented, the mode of transmission of *Serpulina pilosicoli* between pigs is poorly understood. A major risk factor for PCS is a history of moving and mixing of weaner or grower pigs to new accommodations and a change of diet. The current view that *Serpulina pilosicoli* is transmitted by oral exposure to contaminated fecal materials is based on the assumption

Table 1. Survival of *Serpulina hyodysenteriae* and *Serpulina pilosicoli* in spiked fecal pools held at four different temperatures over 63 days.

Temperature	Strain/replicates		Positive (+) or negative (-) culture results from day 0 to day 63 of incubation												
			0	1	3	5	7	14	21	28	35	42	49	56	63
-158°F	*S. hyodysenteriae*	1	++	++	++	--	--	--	--						
		2	++	-+	--	+-	--	--	--						
	S. pilosicoli	1	++	++	++	++	++	++	--	--	-+	+-	-+	--	--
		2	++	++	+-	--	--	--	--	--	--	+-	--	--	--
39°F	*S. hyodysenteriae*	1	++	++	+-	+-	+-	--	--	--					
		2	++	++	--	--	--	--	--	--					
	S. pilosicoli	2	++	++	++	++	++	++	--	--	--				
		2	++	++	++	++	++	+-	--	--	--				
75°F	*S. hyodysenteriae*	1	++	++	--	+-	--	--	--						
		2	++	--	--	--	--	--	--						
	S. pilosicoli	1	++	++	++	++	-+	--	--	--					
		2	++	++	--	--	--	--	--						
99°F	*S. hyodysenteriae*	1	++	-+	--	--	--	--							
		2	++	--	--	--	--	--							
	S. pilosicoli	2	++	++	-+	--	--	--							
		2	++	-+	--	--	--	--							

Replicates: 1 = duplicates of spiked finisher pig fecal pool; 2 = duplicates of spiked grower pig fecal pool.

that the spirochetes remain viable after shedding in the environment. However, with the exception of *Serpulina hyodysenteriae*, little is known about the survival of spirochetes outside of the pig's body. The purpose of this study was to compare the viability of *Serpulina pilosicoli* in pure culture or mixed with feces at four different temperatures over time with that of *Serpulina hyodysenteriae*.

Materials and Methods

Stock cultures of *Serpulina pilosicoli* and *Serpulina hyodysenteriae* were propagated using a standard protocol for anaerobic culture of spirochetes in a liquid medium. The optical density, total bacterial count, viability count and purity of each stock culture were determined by standard laboratory methods.

Fecal materials were collected from four healthy pigs: two finisher (230 pound) and two grower (110 pound) pigs, fed a corn/soybean meal-based diet without a antimicrobial. Pigs were selected on the basis of prior spirochetes-negative fecal cultures. The fecal specimens were refrigerated until the next day when two pools, a finisher and a grower pig fecal pool, were prepared. Spiked fecal pools were prepared by mixing ten times concentrated spirochete cultures with ten times the volume of fecal pool using a mechanical mixer. Four replicates of each pure culture and duplicates of each spiked fecal pool were aliquoted into sterile tubes and held at either -158°F, 39°F, 75°F or 99°F until processing for determination of viability on day zero (sample preparation), one, three, five, seven and at weekly intervals until day 63. The viability of the spirochetes was determined by anaerobic incubation of aliquots of either pure culture or spiked fecal pool onto selective agar medium. Each culture was evaluated blindly after a two-, four- and seven-day incubation period and recorded as positive or negative for the presence of spirochetes.

Results

The pure cultures of *Serpulina pilosicoli* and *Serpulina hyodysenteriae* contained approximately 3 X 10^{11} and 4 X 10^{10} spirochetes per ml, respectively. Pure cultures of both spirochetes survived for the entire observation period of 63 days at -158°C, whereas survival at 39°F was reduced to seven to 14 days for both spirochetes. At 75°F and 99°F, *Serpulina pilosicoli* survived for 14 to 28 days and seven to 28 days, whereas *Serpulina hyodysenteriae* survived for less than one day at each temperature.

The viability of *Serpulina hyodysenteriae* and *Serpulina pilosicoli* in each spiked fecal pool held at each temperature over 63 days is presented in Table 1. Overall, *Serpulina pilosicoli* kept under identical conditions survived longer than *Serpulina hyodysenteriae*. However, the viability of each spirochete held at 75°F and 99°F over time was markedly reduced when inoculated into the grower pig fecal pool when compared with the finisher pig fecal pool (Table 1). Both spirochetes were recovered from all of the spiked fecal pools on the day of inoculation (day zero), but *Serpulina hyodysenteriae* survived less than five days at -158°F, 39°F and 75°F, and less

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than one day at 99°F. Although *Serpulina pilosicoli* showed a gradual loss of viability with increasing temperatures over time, it survived up to 49 days at -158°F, 14 days at 39°F, one to seven days at 75°F and less than three days at 99°F.

Discussion

The results of this study indicate *Serpulina pilosicoli* survives longer than *Serpulina hyodysenteriae* in pure cultures held at 75°F and 99°F, and at all temperatures in spiked fecal materials. Reduced viability of both spirochetes was found in spiked feces over time, an effect was more marked at 75°F and 99°F, and possibly attributable to a direct effect of temperature on the viability of spirochetes exposed to ambient air. However, in a biological model such as spiked feces, the interaction of the spirochetes with the normal fecal bacteria may require rapid induction of adaptative survival mechanisms. For example, the number of bacteria in normal human feces is estimated at 10^{11} per gram, therefore competition with the resident bacteria for limited nutrients may be involved. Additionally, the source of the fecal pools appeared to have an effect on the viability of the spirochetes; the viability of each spirochete was less over time when held at 75°F and 99°F in the grower pig fecal pool compared with the finisher pig fecal pool. The reason for this variation is unknown.

Determination of the duration of potential infectivity of *Serpulina pilosicoli* is critical to management practices such as all-in/all-out and optimal timing for reintroduction of pigs after cleaning. Although the viability of *Serpulina pilosicoli* in fecal materials obtained from naturally infected pigs would have to be examined before definitive conclusions can be made, the data suggested at least seven days may be required for elimination of *Serpulina pilosicoli* from the environment without decontamination.

Serpulina pilosicoli can be isolated from the large intestine of challenge-inoculated pigs for up to six weeks post-inoculation, even though diarrhea may have ceased. This suggests transmission of PCS is from shedding of *Serpulina pilosicoli* in the feces of persistently infected pigs. Carrier-shedder pigs are an important reservoir of *Serpulina pilosicoli* on infected farms, and movement of infected pigs is the most likely means of transmission of *Serpulina pilosicoli* between farms. However, considering *Serpulina pilosicoli* is viable for up to 14 days at less than 39°F, transmission by contaminated fecal material also is likely to occur between groups of pigs or between pens, particularly during winter. This is consistent with high prevalence of clinical signs of PCS in management systems that favor fecal-oral recycling, such as open-flush gutters and recycled lagoon water.

In all-in/all-out multi-site production systems, transmission most likely results from commingling susceptible and shedder pigs. In continuous flow production systems, spirochetes are most likely transmitted by feces from older pigs coming in contact with younger *Serpulina pilosicoli*-naive pigs or from the contaminated environment. Indirect transmission arising from contaminated vehicles or movement of personnel with contaminated clothes or boots also is possible. The possibility also exists that hosts other than pigs may act as potential sources of *Serpulina pilosicoli*, emphasizing the need for biosecurity. Access of dogs, mice and wildlife, including birds, to the pigs and feedstuffs should be restricted.

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Feasibility of Growing and Feeding High Oil Corn to Pigs

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Summary and Implications

A feasibility analysis on the growing and feeding of high-oil corn (HOC) to pigs was conducted. The cost to produce HOC is about 25 to 32 cents per bushel higher than for normal corn (NC), primarily due to 7 to 10 percent yield reduction for HOC. Diets made with HOC contain between 1.5 and 3 percent additional fat. Therefore, feed efficiency should be improved, on average, by 3 to 6 percent when HOC is substituted for NC. In most cases, daily gain should improve by 0 to 3 percent with HOC in the diet. High-oil corn grown in central Nebraska during 1997 averaged 6.2 percent oil (12 percent moisture). When HOC (6.2 percent oil) is used to replace NC in growing-finishing pig diets, it is worth 21 to 25 cents more than NC, assuming NC and 44 percent protein soybean meal cost $2.50 per bushel and $250 per ton, respectively. When NC and soybean meal cost $2 per bushel and $200 per ton, HOC is worth 17 to 20 cents more than NC. If HOC is used to replace animal or vegetable fat in pig diets, it is worth about 40 cents per bushel more than NC, if supplemental fat costs 20 cents per pound. The only economic benefit given to HOC was an increase in feed efficiency. These results suggest no

current economic incentive for producers to grow and feed HOC.

Introduction

High-oil corn (HOC) is the fastest growing segment of the value-enhanced corn market. DuPont is the primary company involved in HOC production, having licensed its HOC genes to 80 seed companies. The DuPont TOPCross system is the most common method of producing commercial HOC. This method involves planting a blend of two types of corn, the "grain parent" and the "pollinator."

The purpose of this study is to determine whether or not it is cost effective to raise HOC and feed it to pigs. In addition, the value of HOC as a fat source versus other sources of supplemental fat will be presented. Because of the limited amount of research results available on both the production and feeding of HOC, this is a progress report.

Producing High-Oil Corn

In general, the same production practices recommended for normal corn (NC) apply to HOC. TOPCross hybrids depend on the transfer of pollen from a male parent (the pollinator) to the male-sterile female parent (the grain parent). The males make up only 8 to 10 percent of the blends, so the number of plants contributing to pollen production is reduced. Some precautions with HOC may he warranted to ensure successful pollination, such as planting away from NC, to avoid cross pollination with low-oil types. There is, however, disagreement over the extent of separation needed, with estimates ranging from 0 to 200 feet.

Some people recommend an increased seeding rate for HOC. There is no good evidence to indicate optimum seeding rates for TOPCross corn are higher than for NC. Seeding rates above the optimum in dryland production can increase the severity of drought stress during pollination.

A HOC hybrid is likely to yield less than its low-oil counterpart. The yield loss is expected because of two factors: the physiological cost of making the oil and the competition between the male and female parents in blended hybrids.

In the process of making oil instead of carbohydrate, carbon is lost. The loss of carbon is wasteful, so plant synthesis of corn oil is less efficient than carbohydrate production. All other things being constant, a 2.5 percent yield reduction would be expected for every I percent increase in oil content.

The second source of yield reduction is from the mixing of plants contributing to yield (the female parents) with plants that only contribute pollen. The male plants, which make up 8 to 10 percent of the blends, use resources — light, water and nutrients — at the expense of their neighbors. If the male and female parents are similar in size, the light intercepted by the female parent is likely to be reduced in proportion to the amount of the male pollinator present. Given the direct effect of light interception on photosynthesis, and photosynthesis on yield, a loss of approximately 8 to 10 percent can be expected.

Because the yield of HOC compared to NC is uncertain, it may be best to evaluate the impact of a range of yield reductions. It appears HOC will likely yield within a range of 85 to 100 percent of NC. That range was selected for evaluation and the results are presented in Table 1.

Because the production practices for HOC and NC are identical (except for isolation), the production costs per acre are the same, except for the seed. There is often a $30 per bag technology fee for HOC seed. This amounts to about $10 per acre. If HOC yields the same as NC, this $10/acre is the only added cost, and this amounts to 6.8 cents per bushel with a 150 bu/acre yield (Table 1). But, the HOC will most likely yield less than NC, resulting in fewer bushels with a slightly higher per acre cost. The decreased yield has much more impact on the production cost of HOC than does the technology fee on the seed. If HOC yield is of 90 percent of NC yield, the added production cost is 32.5 cents per bushel (this includes the 6.8 cent cost due to the technology fee). The added production costs would increase slightly if seeding rate was increased by 2,000 seeds per acre. Thus, the yield of HOC producers can expect is a key variable in their decision to adopt this technology.

Table 1. Added production cost (cents/bushel) of high oil corn (HOC) compared to normal corn (NC)[a].

Yield, Percent of NC	100	95	90	85
Planting rate of HOC				
Same as NC	6.8	19.6	32.5	45.4
+ 2,000 seeds per acre	7.3	20.1	33.1	46.0

[a]Technology fee of seed, $30 per bag; yield of NC, 150 bushels/acre; planting rate of NC, 27,000 seeds/acre; cost of production for NC, $2.50/bushel.

Yield comparisons of HOC to NC are difficult to make, due to the isolation needed for HOC. In a study in Ohio, the average yield of high-oil varieties was 90 percent of the NC hybrids. Two NC hybrids in this experiment had high-oil counterparts. Considering only these two hybrids, the high oil versions averaged 92.3 percent of the yield of the NC hybrids.

The Kearney (Nebraska) Area Agricultural Producers Alliance conducted evaluations in six locations in 1997. The large plot tests contained up to 16 HOC varieties and two to four NC hybrids for yield comparison. The six plot average yield of HOC oil varieties was 90.8 percent of the average of NC yields.

Therefore, it seems that yields will likely be in the 90 to 93 percent range, given the current stage of the technology. This would result in added production costs of 25-32 cents per bushel for HOC.

The storage requirements for HOC are similar to those for NC. To gain the most benefit from feeding HOC, it

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must be stored separately from NC. This may result in additional cost or inconvenience for some producers.

Feeding High-Oil Corn to Pigs

Nutrient Composition and Quality

The nutrient composition of HOC and NC are similar with a few important exceptions. High oil corn contains more protein, lysine, fat and metabolizable energy than NC (Table 2). Because there seems to be significant genetic and environmental effects on the final nutrient content of HOC, a range in composition is presented.

Effect of High-Oil Corn in Swine Diets

Few data exist comparing the performance of pigs fed HOC (5.5 to 7.5 percent oil) to NC (3.5 to 4.2 percent oil). However, a large database exists on the effect of adding animal fat or vegetable oil to swine diets. Recent trials indicate pig performance is similar when the total amount of fat in NC-based diets is equalized to a HOC-based diet by fat supplementation. From this, we assume HOC in the diet would elicit a response similar to that observed when a similar amount of fat is added to a NC-based diet.

On the average, feed efficiency is improved by 2 percent for each 1 percent increment of added fat to the diet. Diets containing HOC contain between 1.5 and 3 percent added fat, depending on the oil content of the corn. Therefore, feed efficiency should be improved by about 3 to 6 percent when HOC is substituted for NC corn.

Generally when growing-finishing pigs are fed NC-based diets containing 1.5 to 3.0 percent added vegetable oil or animal fat (amount similar to that when HOC replaces NC in the diet), daily gain remains constant. In some cases, especially during hot weather, daily gain may increase up to about 3 percent. Until further data from HOC feeding trials are available, we suggest average daily gain will remain the same or may improve up to 3 percent when HOC replaces NC in growing-finishing pig diets.

Backfat thickness should not be altered when using HOC in the diet, unless the additional fat levels exceed 5 percent of the diet and the amino acid: calorie ratio in the diet is not maintained constant.

Because some producers may not have enough HOC to feed all of their pigs, they need to decide how to best utilize the corn in their operation. In general, growing pigs weighing from about 30 to 130 pounds and lactating sows would benefit the most from HOC as they have the most difficulty consuming enough calories to maximize performance.

As little as 2.5 percent added fat (50 pounds/ton) reduces dust in confinement buildings by about 25 percent. Reduced dust levels have improved health implications for both pigs and people. Also, small additions of fat in an ingredient or feed allows it to flow more easily.

Estimating the Economic Value of High-Oil Corn

In our analysis we credited HOC for improving feed efficiency only. Given the potential variation in the oil content of HOC varieties and in factors affecting feed conversion rates, economic values were estimated for a range of outcomes (Table 3).

Producers should use the results from the oil analysis of their HOC to choose which type is most like theirs (5.5 or 7.5 percent oil). For each type of HOC, a range in the improvement in feed efficiency is included in the analysis. Producers could, in some instances, expect a greater response in feed efficiency. For example, feed efficiency and daily gain are improved more by feeding fat to pigs during summer than during winter. If pigs are expected to be finished during the summer, it would be better to assume feed efficiency may improve by 7 percent (for 7.5 percent HOC). During the winter, however, the same HOC may only produce a 5 percent improvement in feed efficiency.

To calculate the economic value of HOC as a replacement for NC in growing-finishing pig diets, a total of 12 diets were formulated. All the diets contained 44 percent crude protein soybean meal as the sole source of supplemental protein. Four diets were formulated with NC to contain 1.00, .9, .8 and .7 percent lysine. Four diets were formulated with 5.5 percent fat HOC and four others with 7.5 percent fat HOC. The HOC-based diets contained the same ratio of lysine to metabolizable energy as the NC-based diets. An overall feed conversion rate of 3.0 pounds feed per pound of gain and an average daily gain of 1.8 pounds was assumed. The improvements in feed efficiency shown in Table 3 were applied to the HOC diets. The price of NC was $2.50/bu, 44 percent soybean meal was $250/ton, and other ingredients were at current market prices. The cost savings realized from improved feed conversion was attributed to HOC. Results are shown in Table 4.

Because the advantage of HOC results from an improvement in feed efficiency, the price of the major ingredients (corn and soybean meal) affect the added value of the HOC. To show impact of changes in ingredient prices, a range of added values for HOC, reflecting high and low corn and soybean meal prices is shown in Table 4.

Table 2. Composition of high-oil corn (HOC) and normal corn (NC)[a].

Item	HOC	NC
Protein,%	8.6 to 8.8	8.3
Lysine.%	.28 to 30	.26
Fat, %	5.5 to 7.5	3.9
Metabolizable energy, kcal/lb	1,580 to 1,635	1,555

[a]As-fed basis (12 percent moisture).

Table 3. Expected improvement in feed efficiency from feeding high-oil corn.

Corn oil content, percent[a]	Improvement in feed efficiency, percent
5.5	2 to 4
7.5	5 to 7

[a]12 percent moisture.

Table 4. Value (cents per bushel) of high-oil corn (HOC) compared to normal corn (NC).

Corn oil content, percent[a]	Improvement in feed efficiency, percent	Added value of HOC, cents/bu	
		Value	Range[b]
5.5	2	11	9 to 13
	4	21	17 to 35
7.5	5	25	20 to 29
	7	35	28 to 41

[a]12 percent moisture.
[b]Range in HOC values reflects a range of prices for NC corn and 44 percent soybean meal.
Low prices; NC = $2/bu and 44 percent soybean meal = $200/ton
High prices; NC = #3/bu and 44 percent soybean meal = $300/ton

Table 5. Potential added value of high-oil corn (HOC) due to a 3 percent increase in average daily gain.

Savings per pig per day, cents	Added value of HOC, cents per bushel
0	0
5	2
10	4

[a]Assumes no change in the through put of the building. The timing of pig placements is kept the same. Potential savings due to the shorter feeding period are in interest, utilities, and possibly labor.

Table 6. Value of high-oil corn (HOC) compared to normal corn (NC) at various supplemental fat prices[a].

Fat price, cents/pound	Added value of HOC, cents/bushel
10	21
20	44
30	67
40	89

[a]NC = $2.50/bu; 44% soybean meal = $250/ton; feed efficiency with NC and no added fat = 3.0 lb feed/lb gain; HOC - 7.5% oil, 0.3% lysine.

For example, if a 5 percent improvement in feed efficiency is achieved, the added value of HOC is 25 cents per bushel (with $2.50/bu corn and $250/ton soybean meal). But, the HOC advantage drops to 20 cents/bu if NC is $2/bu and soybean meal is $200/ton.

The average oil content of HOC varieties in the Kearney Area Agricultural Producers Alliance field tests was 6.2 percent (12 percent moisture basis). Thus, feed efficiency should improve by 4 to 5 percent when fed to growing-finishing pigs. This would result in an added value of HOC of 21-25 cents (with $2.50/bu corn and $250/ton soybean meal). Earlier, we concluded that production costs would likely be 25 to 32 cents per bushel higher for HOC. Thus, growing and feeding HOC to swine does not seem to be economically feasible at the current state of the technology and recognizing increased feed efficiency as the only economic benefit.

The Effect of Increased Average Daily Gain

If pigs that are fed a diet containing HOC gain 3 percent faster than those fed diets containing NC, what is the economic benefit? The effect of an increase in average daily gain is analyzed as a "what-if" question, since the variability in feeding trial results does not produce a clear answer. In addition to uncertainty regarding any change in average daily gain, the economic value of reducing the length of the feeding period varies from producer to producer.

If producers obtain a 3 percent increase in average daily gain, they will likely realize an added value of HOC in the 0 to 2 cents per bushel range (Table 5). While an improvement in average daily gain is possible, it is doubtful most producers are able to derive a significant economic benefit from it.

High-Oil Corn Versus Other Sources of Added Fat

Producers who currently add fat to their pig diets can substitute HOC for NC to achieve the higher dietary fa levels. What is the economic value of HOC when it is used to replace added fat (animal or vegetable) and NC in pig diets? To answer this question, diets were formulated with NC and fat to contain the same metabolizable energy lysine and fat level as diets with 7.5 percent oil HOC. Diets were formulated in the same manner as described previously. Prices of $2.50/bu for NC and $250/ton for 44 percent soybean meal were used. Fat prices of 10, 20,30 and 40 cents per pound were used in the analysis. The economic value of HOC, compared to NC was calculated for each of the fat prices (Table 6).

The added values, or premiums, for HOC, when used to replace added fat (Table 6) are much greater than those when it was substituted for NC (Table 5). A fat price of 20 cents per pound results in a 44 cent/bu premium for HOC, clearly above the 25-32 cents/bu increase in production cost. Vegetable oils, which may cost 40 cents/pound, result in an 89 cent/bushel premium for HOC.

Producers should use caution when interpreting the premiums for HOC in Table 6. It is assumed the producer can justify purchasing fat at, for example, 20 cents per pound and adding it to the diet. Therefore, if HOC can be included in the diet for less than a 44 cents per bushel premium, fat can be acquired less expensively with HOC. Table 4 simply allows one to determine quickly if HOC is more economical. It does not imply it is economically feasible to add fat at the prices shown.

Conclusion

High-oil corn is a developing technology. Results to date suggest that it may yield 90 to 93 percent of NC, resulting in a production cost 25 to 32 cents per bushel higher than NC. Producers might expect the fat content of HOC to range from 5.5 to 7.5 percent with an average fat content of 6.2

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percent (12 percent moisture basis). If the HOC is used to replace NC in growing-finishing pig diets, it is worth 21-25 cents more than NC, given a $2.50/bu price for NC and $250/ton for 44 percent soybean meal, and assuming the only economic benefit of HOC is an increase in feed efficiency. If HOC is used to replace animal or vegetable fat in pig diets, it is worth about 40 cents per bushel more than NC, if supplemental fat costs 20 cents per pound.

The current situation does ont encourage pork producers to grow and feed HOC. Further research is needed to verify the comparative yield level and oil content of HOC, as well as the variance of these measures. Additional field trials may decrease the variance between the expected versus actual yields and oil contents. In addition, further research may reduce or eliminate the yield gap between HOC and NC.

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Bioavailability of Iron in Iron Proteinates

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Phillip S. Miller
Hsin-Yi Chen[1]

Summary and Implications

The bioavailability of the iron in two different sources of iron proteinate was compared with that in feed-grade iron sulfate ($FeSO_4 \cdot H_2O$). Pigs, which were iron deficient and anemic at weaning, were given diets with no supplemental iron or supplements, of iron sulfate or iron proteinate. During the three-week study, weight gain and hemoglobin increased as the iron supplementation increased. When hemoglobin repletion was compared, there were no significant differences between iron sulfate and either of the iron proteinate sources. These results indicate the iron in iron sulfate and the two iron proteinate sources were similar in bioavailability. Thus, price per unit of total iron should be the primary criterion when selecting among these iron sources.

Introduction

Iron is a critical trace mineral for young pigs because the iron content of sows' milk is very low. Most newborn pigs are given an iron injection to meet their needs until weaning. After weaning, supplemental iron must be provided because the iron content of most diet ingredients is not adequate to meet needs, especially during periods of rapid growth.

The most commonly used source of supplemental iron, iron sulfate ($FeSO_4 \cdot H_2O$), is relatively inexpensive and in a form readily available to the animal (bioavailable). However, other iron sources are available. Many of which are referred to as "organic" because the iron is combined with an organic molecule such as an amino acid or protein. Organic sources are usually more expensive per unit of total iron than inorganic sources and therefore must offer some advantage to justify including them in swine diets. Increased bioavailability of the iron in organic sources would justify their purchase and inclusion in swine diets.

In a previous experiment (Nebraska Swine Report 1996), we evaluated the bioavailability of iron in iron methionine. In the following report, we discuss experiments designed to determine the bioavailability of iron in two different sources of iron proteinate relative to the iron in iron sulfate.

Methods

The methods were the same in both experiments. Pigs selected for the experiments were given no supplemental iron (either oral or injectable) from birth until weaning at approximately 21 days post-farrowing. At weaning, blood hemoglobin concentrations were measured and, based on hemoglobin concentration, 72 barrows and 72 gilts were selected for each experiment. The average initial weights and initial hemoglobin concentrations were 11.6 and 11.1 pounds and 4.5 and 4.0 g/100 mL in Experiments 1 and 2, respectively. The selected pigs were iron deficient and anemic at the start of the experiments, as the normal hemoglobin concentration is 8 to 12 g/100 mL.

During the experimental periods, pigs were allotted to a basal diet (Table 1) or to diets formulated to contain 75 or 150 mg/kg (ppm) of supplemental iron from feed-grade iron sulfate or diets formulated to contain 50, 100 or 150 mg/kg of supplemental iron from iron proteinate. The same source of iron sulfate was used in both experiments. Thus in each experiment there were six dietary treatments. There were 36 pens (six per treatment) with two barrows and two gilts per pen. Pigs were allowed ad libitum access to feed and water throughout the three-week experiment. Pigs were bled at the end of each week and hemoglobin concentrations were determined. Hemoglobin repletion was calculated as ((final weight $\times$ 0.088) $\times$ final hemoglobin) - ((initial weight $\times$ 0.088) $\times$ initial hemoglobin). The factor of 0.088 was used because blood volume was assumed to be 8.8 percent of body weight.

Table 1. Composition and nutrient analysis of the basal diet (as-fed basis).

Item	Amount
Ingredient, percent	
Corn	51.98
Soybean meal, 46.5% CP	5.00
Dried skim milk	30.00
Spray-dried plasma protein	6.00
Corn oil	4.00
Monosodium phosphate	1.00
Limestone	.75
Salt	.25
Trace mineral premix[a]	.02
Vitamin premix[b]	1.00
Analyzed nutrient content	
Crude protein,%	20.9
Lysine,%	1.31
Calcium,%	.82
Phosphorus,%	.77
Iron, mg/kg	65
Copper, mg/kg	10
Zinc, mg/kg	139

[a]Supplied the following amounts of trace elements in milligrams per kilogram of complete diet: Cu (as $CuSO_4 \cdot 5H_2O$), 10; I (as $Ca(IO_3)_2$),m .2; Mn (as MnO), 20; Se (as Na_2SEO_3), .3; and Zn (as ZnO), 100.

[b]Supplied the following amounts of vitamins per kilogram of complete diet; retinyl acetate, 4,400 IU; cholecalciferol, 550 IU; *all-rac-α*-tocopheryl acetate, 22 IU; menadione (as menadione sodium bisulfite complex), 3.3 mg; riboflavin, 5.5 mg; niacine, 33 mg; *d*-pantothenic acid (as *d*-calcium pantothenate), 22 mg; cyanocobalamin, 22µg; and choline (as choline chloride), 110 mg.

Table 2. Effects of iron source and iron supplementation on growth, blood hemoglobin and hemoglobin repletion of weanling pigs (Exp. 1)[a].

Source:		Iron sulfate[b]		Iron proteinate[c]		
Item[d] Supplemental Iron, mg/kg:	0	60.2	163.3	44.8[e]	86.8	141.6
ADG (0 to 3 wk), lb	.004	.238	.379	.128	.287	.337
ADFI (0 to 3 wk), lb	.300	.483	.551	.346	.485	.567
Gain/Feed (0 to 3 wk)	.015	.482	.673	.336	.595	.606
Hb concentration (wk 0), g/dL	4.61	4.36	4.74	4.50	4.59	4.22
Hb concentration (wk 1), g/dL	4.66	4.71	4.82	4.58	4.80	4.62
Hb concentration (wk 2), g/dL	4.11	5.12	5.91	4.42	5.19	5.74
Hb concentration (wk 3), g/dL	4.10	5.78	7.36	4.79	5.95	7.61
Hb repletion (O to 1 wk), g	.46	3.66	2.13	.66	2.69	3.28
Hb repletion (O to 2 wk), g	-2.31	7.72	12.48	1.70	7.39	12.52
Hb repletion (0 to 3 wk), g	-2.12	18.76	36.72	6.24	20.52	37.14

[a]Data represent means of six pens per treatment (each pen contained two barrows and two gilts). Three-week experiment: average initial weight 11.57 lb; average final weight 16.45 lb.

[b]Supplemental iron was provided as feed-grade $FeSO_4 \cdot H_2O$.

[c]Supplemental iron was provided as iron proteinate (OPTiMIN® FE, NutriBasics, Highland, IL).

[d]ADG = average daily gain, ADFI = average daily feed intake, Gain/Feed = feed efficiency, and Hb = hemoglobin.

[e]Mean of five pens because of weight loss in the other pen.

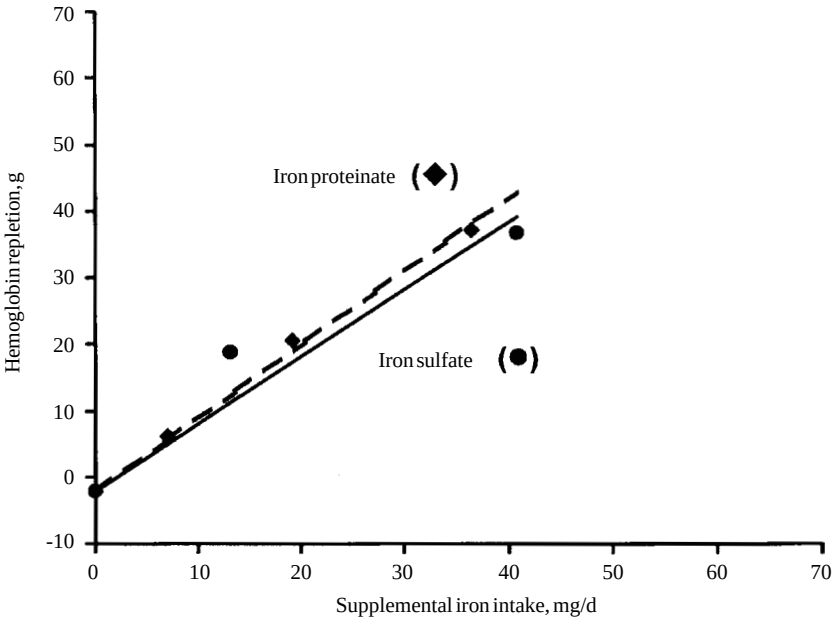

Figure 1. Slope ratio comparison of the effect of iron sulfate and iron proteinate on hemoglobin repletion in weanling pigs (Experiment 1).

Results and Discussion

The results of the first experiment are in Table 2. Chemical analysis of the diets for iron content established the analyzed supplemental iron content differed somewhat from the calculated content. The analyzed contributions from the supplemental sources are shown in Table 2 and these values were used in the analysis of the data. Pigs fed the diet without iron supplementation gained very little weight and their hemoglobin concentration declined as the experiment progressed. Addition of supplemental iron increased weight gain, feed intake and feed efficiency linearly ($P < .001$) regardless of whether the supplemental iron was from iron sulfate or iron proteinate. The changes in growth performance per unit of supplemental iron were approximately equal as well.

Blood hemoglobin concentrations in the first experiment were also affected by iron intake. At the end of the experiment (week three) blood hemoglobin increased linearly ($P < .001$) as the supplemental iron concentration increased. As for the growth traits, the increase in hemoglobin concentration was relatively similar, regardless of supplement source. Hemoglobin repletion, which combines both weight gain and hemoglobin concentration, also increased linearly ($P .001$) as dietary iron content increased. The effects were particularly evident at the end of the experiment.

To calculate relative bioavailabilities, hemoglobin repletion was related to supplemental iron intake. The relationship at the end of Experiment 1 is illustrated in Figure 1. For simplicity, mean values are shown,

Table 3. Effects of iron source and iron supplementation on growth, blood hemoglobin and hemoglobin repletion of weanling pigs (Experiment 2)[a].

Source:		Iron sulfate[b]		Iron proteinate[c]		
Item[d] Supplemental Iron, mg/kg:	0	60.2	163.3	44.8[e]	86.8	141.6
ADG (O to 3 wk), lb	.132	.262	.465	.337	.384	.467
ADFI (0 to 3 wk),lb	.494	.567	.791	.628	.697	.769
Gain/Feed (0 to 3 wk)	.263	.455	.581	.533	.552	.607
Hb concentration (wk 0), g/dL	3.84	4.27	3.73	4.25	3.80	4.16
Hb concentration (wk 1), g/dL	3.78	4.50	4.07	4.55	4.42	5.52
Hb concentration (wk 2), g/dL	3.93	5.03	6.55	5.09	5.80	7.40
Hb concentration (wk 3), g/dL	4.04	6.29	9.28	5.86	7.95	9.45
Hb repletion (0 to 1 wk), g	.92	2.43	9.61	3.98	5.25	10.32
Hb repletion (0 to 2 wk), g	2.50	8.14	24.84	10.72	18.39	28.42
Hb repletion (0 to 3 wk), g	5.29	23.01	62.27	24.71	44.16	60.03

[a]Data represent means of six pens per treatment (each pen contained two barrows and two gilts). Three-week experiment: average initial weight 11.11 lb; average final weight 18.28 lb.
[b]Supplemental iron was provided as feed-grade $FeSO_4 \cdot H_20$.
[c]Supplemental iron was provided as iron proteinate (BUFFERMIN®, JH Biotech, Inc., Ventura, CA).
[d]ADG = average daily gain, ADFI = average daily feed intake, Gain/Feed = feed efficiency, and Hb = hemoglobin.

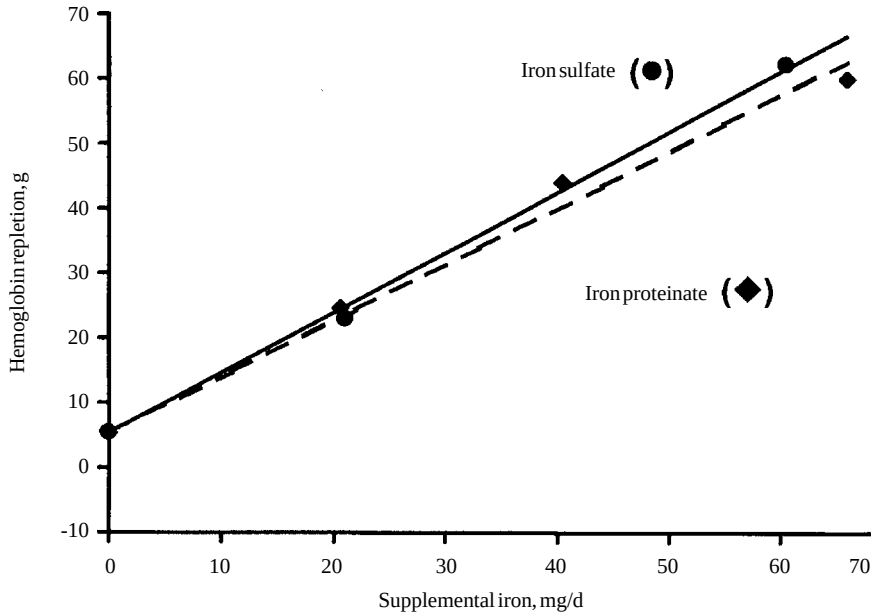

Figure 2. Slope ratio comparison of the effect of iron sulfate and iron proteinate on hemoglobin repletion in weanling pigs (Experiment 2).

although statistical calculations were done on individual pens. The increases in hemoglobin repletion were slightly greater for iron proteinate than for iron sulfate. Statistical analysis revealed the ratio of the two slopes was 1.03, meaning iron proteinate was 103 percent as bioavailable as iron sulfate. However, 103 percent was not statistically different from 100 percent, indicating the two sources were similar in iron bioavailability.

Results of the second experiment are in Table 3 and Figure 2. These results were very similar to Experiment 1. Both growth performance and blood hemoglobin concentration increased linearly ($P < .001$) as supplemental iron increased. As shown in Figure 2, the increase was somewhat lower for iron proteinate than for iron sulfate. The ratio of the slopes of the two lines was 0.92, revealing this source of iron proteinate was 92 percent as bioavailable as iron sulfate. As in Experiment 1, this value was not statistically different from 100 percent, indicating the two sources are similar in iron bioavailability.

The results of these two experiments indicate iron sulfate and the two sources of iron proteinate contain iron equally bioavailable to meet the needs of weanling pigs.

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Zinc Oxide, With or Without Carbadox, Stimulates Performance in Nursery Pigs

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Summary and Implications

As part of a cooperative research study with several other Midwest universities, two experiments were conducted to evaluate the effects of high concentrations of zinc from zinc oxide in nursery diets. In the first experiment, the effects of adding various pharmacological concentrations of zinc as zinc oxide were tested. In the second experiment, the effects of both zinc and(or) carbadox additions to diets for weanling pigs were evaluated. Feeding pharmacological concentrations (2,000 to 3,000 mg/kg) of supplemental zinc from zinc oxide stimulated voluntary feed intake and weight gain of nursery pigs, but additive responses to carbadox (55 mg/kg) were not observed. In this experiment, supplementing weanling pigs diets with carbadox had no effect on growth performance. Based on this study, zinc oxide is more cost-effective than carbadox for promoting growth in weanling pigs.

Introduction

Zinc is one of the trace minerals routinely supplemented to swine diets to meet pigs nutritional requirements. Recently, several researchers have reported pharmacological concentrations of zinc (Zn) as zinc oxide (ZnO) improved growth performance during the nursery phase. In addition, carbadox is commonly added to nursery pig diets to promote growth and control certain pathogenic organisms. The objectives of our studies were to evaluate the effects of various concentrations of Zn as ZnO, as well as the potential interactive or additive effects of Zn and carbadox on weanling pig performance. Although these experiments were part of a larger research project involving several Midwest universities, only the Nebraska results are described in this report.

Methods

Experiment 1.

A total of 300 segregated, early weaned (SEW) pigs (170 barrows and 130 gilts) that were 9 to 13 days of age and weighed 8.6 pounds were used in a 28-day growth trial. Pigs were blocked on the basis of farrowing date and allotted to one of five treatments (0, 500, 1,000, 2,000 and 3,000 mg/kg of Zn as ZnO) with 20 pigs per pen and three replications (pens) per treatment. The Phase 1 diets were fed from week zero to two, followed by the Phase 2 diets from week two to four.

Experiment 2.

The purpose of the second experiment, which used 240 pigs, was to determine whether pharmacological concentrations of Zn have an additive effect when fed in combination with carbadox. The 120 barrows and 120 gilts used in the 28-day growth trial had an average initial weight of 15.5 pounds. Pigs were weaned from 19 to 26 days of age and assigned to blocks based on farrowing date. Within each of the two blocks, pigs were randomly assigned to treatments with 20 pigs per pen and two replications (pens) per treatment. Treatments were arranged in a 2×3 factorial with main effects of added Zn (0, 1,500, or 3,000 mg/kg) and carbadox (0 or 55 mg/kg). The Phase 1 diets were fed from week zero to one, then the Phase 2 diets from week two to four.

Table 1. Composition and nutrient analysis of the basal diets in Experiment 1 (as-fed basis)[a].

Item	Phase 1	Phase 2
Ingredient, percent		
Corn	40.64	54.19
Soybean meal (46.5% CP)	19.00	19.50
Whey, dried	20.00	20.00
Plasma, spray-dried	6.00	—
Lactose	10.00	—
Blood meal, spray-dried		2.00
Corn oil	1.00	1.00
L-lysine.HC1	.15	.15
DL-methionine	.11	.06
Dicalcium phosphate	1.45	1.45
Salt and trace mineral[b]	.45	.45
Vitamin premix	1.00	1.00
Aureomycin-50	.20	.20
Nutrient content		
Crude protein, %	19.90	18.20
Lysine, %	1.39	1.20
Calcium, %	.80	.80
Phosphorus, %	.75	.70
Zinc, mg/g	129.00	132.00
Copper, mg/kg	18.60	19.30
Iron, mg/kg	188.00	248.00

[a]Composition of the basal diets. The other four diets in each phase contained additions of 500, 1,000, 2,000 and 3,000 mg/kg zinc from zinc oxide.
[b]Supplied the following amounts of trace elements in milligrams per kilogram of complete diet: Cu (as $CUSO_4 \cdot 5H_2O$) 10; I (as $Ca(IO_3)_2$), .2; Mn (as MnO), 20; Se (as Na_2SeO_3), .3; and Zn (as ZnO), 100.
[c]Supplied the following amounts of vitamins per kilogram of complete diet: retinyl acetate, 4,400 IU; cholecalciferol, 550 IU; *all-rac-α*-tocopheryl acetate, 22 IU; menadione (as menadione sodium bisulfite complex), 3.3 mg; riboflavin, 5.5 mg; niacin, 33 mg; *d*-pantothenic acid (as *d*-calcium pantothenate), 22 mg; cyanocobalamin, 22µg; and choline (as choline chloride), 110 mg.
[d]Calculated.

Experimental Diets.

All diets were fed in a meal form. The nutritional compositions of these diets are given in Table 1 (Exp. 1) and

(Continued on next page)

Table 2. Composition and nutrient analysis of the basal diets in Experiment 2 (as-fed basis)[a].

Item	Phase 1	Phase 2
Ingredient, percent		
Corn	35.15	47.15
Soybean meal (46.5% CP)	14.00	20.00
Whey, dried	25.00	20.00
Plasma, spray-dried	6.00	—
Soy protein concentrate	4.80	—
Blood meal, spray-dried	1.00	3.50
Lactose	10.00	5.00
Soybean oil	1.00	1.00
L-lysine.HCl	.10	.10
DL-methionine	.05	.05
Dicalcium phosphate	1.10	1.55
Limestone	.45	.30
Salt and trace mineral[b]	.35	.35
Vitamin premix[c]	1.00	1.00
Nutrient content[d]		
Crude protein, %	21.80	19.30
Lysine, %	1.54	1.28
Calcium, %	.94	.94
Phosphorus, %	.71	.71
Zinc, mg/kg	128.00	132.00
Copper, mg/kg	18.80	19.30
Iron, mg/kg	218.00	290.00

[a]Composition of the basal diets. The other five diets in each phase contained additions of zinc (1,500 or 3,000 mg/kg) or carbadox (55 mg/kg).
[b]Supplied the following amounts of trace elements in milligrams per kilogram of complete diet: Cu (as $CuSO_4 \cdot 5H_2O$), 10; I (as $Ca(IO_3)_2$), .2; Mn (as MnO), 20; Se (as Na_2SeO_3), .3; and Zn (as ZnO), 100.
[c]Supplied the following amounts of vitamins per kilogram of complete diet: retinyl acetate, 4,400 IU; cholecalciferol, 550 IU; *all-rac-α*-tocopheryl acetate, 22 IU; menadione (as menadione sodium bisulfite complex), 3.3 mg; riboflavin, 5.5 mg; niacin, 33 mg; *d*-pantothenic acid (as *d*-calcium pantothenate), 22 mg; cyanocobalamin, 22µg; and choline (as choline chloride), 110 mg.
[d]Calculated.

Table 2 (Exp. 2). Zinc oxide and/or carbadox replaced corn in the diets. Within each phase, dietary crude protein, lysine, methionine, Ca and P were kept constant.

Management.

In both experiments, pigs were housed in environmentally controlled nurseries and were allowed ad libitum access to feed and water. Weight gain and feed intake were measured weekly to determined average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (ADFI/ADG).

Table 3. Effects of zinc supplementation on growth performance of weanling pigs (Experiment 1).[a].

	Supplemental Zinc Concentration, mg/kg[b]					P-value[d]	
Item[c]	0	500	1,000	2,000	3,000	L	Q
Phase 1 (0 to 2 week)							
ADG, lb/d	.295	.289	.291	.407	.418	< .005	NS
ADFI, lb/d	.496	.469	.479	.558	.560	< .05	NS
ADFI/ADG	1.697	1.637	1.686	1.381	1.351	< .005	NS
Phase 2 (2 to 4 week)							
ADG, lb/d	.551	.665	.706	.840	.833	< .005	< .005
ADFI, lb/d	.855	.971	.989	1.209	1.262	< .005	NS
ADFI/ADG	1.559	1.463	1.404	1.439	1.514	NS	NS
Overall (0 to 4 week)							
ADG, lb/d	.423	.477	.498	.623	.626	< .005	< .01
ADFI, lb/d	.675	.720	.734	.884	.911	< .005	NS
ADFI/ADG	1.597	1.509	1.478	1.416	1.454	< .05	< .05

[a]Data represent means of three pens per treatment (each pen contained 20 pigs, the ratio of barrow:gilt was either 11:9 or 12:8). Four-week experiment: average initial weight 8.57 lb; average final weight 23.39 lb.
[b]Supplemental zinc was provided as zinc oxide.
[c]ADG = average daily gain, ADFI = average daily feed intake.
[d]L = linear effect, Q = quadratic effect, and NS = nonsignificant effect.

Table 4. Effects of carbadox and zinc supplementation on growth performance of weanling pigs (Experiment 2).[a].

	Treatment[b]						Effect of zinc	
Carbadox, mg/kg:	0	0	0	55	55	55	P-value[d]	
Item[c] Zinc: mg/kg:	0	1,500	3,000	0	1,500	3,000	L	Q
Phase 1 (0 to 1 week)								
ADG, lb/d	.278	.266	.323	.297	.223	.261	NS	NS
ADFI, lb/d	.386	.357	.416	.398	.334	.362	NS	< .05
ADFI/ADG	1.650	1.765	1.322	1.478	1.771	1.764	NS	NS
Phase 2 (1 to 4 week)								
ADG, lb/d	.841	.911	.989	.834	1.012	.951	NS	NS
ADFI, lb/d	1.209	1.371	1.499	1.210	1.449	< .005	NS	
ADFI/ADG	1.441	1.509	1.516	1.451	1.411	1.530	NS	NS
Overall (0 to 4 week)								
ADG, lb/d	.701	.750	.823	.699	.815	.779	NS	NS
ADFI, lb/d	1.003	1.118	1.229	1.007	1.155	1.177	< .005	NS
ADFI/ADG	1.432	1.489	1.494	1.438	1.420	1.526	NS	NS

[a]Data represent means of two pens per treatment (each pen contained 10 barrows and 10 gilts). Four-week experiment: average initial weight 15.48 lb; average final weight 36.82 lb.
[b]Supplemental zinc was provided as zinc oxide.
[c]ADG = average daily gain, ADFI = average daily feed intake.
[d]L = linear effect, Q = quadratic effect, and NS = nonsignificant effect. No effects of carbadox were observed.

Results and Discussion

Experiment 1.

From week zero to two after weaning, increasing Zn concentration linearly increased ADG and ADFI and decreased ADFI/ADG (Table 3). From week two to four, increasing ZnO improved ADG up to the 2,000 mg/kg treatment. Average daily feed intake increased slightly as Zn increased from 2,000 to 3,000 mg/kg. For the overall experiment (week zero to four), increasing Zn increased ADG and ADFI and decreased ADFI/ADG. However,

most of the improvement of ADG and ADFI/ADG was achieved with 2,000 mg/kg Zn, with little or no further improvement as Zn concentration in creased from 2,000 to 3,000 mg/kg. These results suggest pharmacological concentrations of Zn from ZnO are beneficial in the diets of SEW pigs. It was apparent the weight gain responses resulted primarily from increased voluntary feed intake. The mechanism for the feed intake response was not determined in this experiment, however, other reports suggest such improvements may be due to more healthy gut tissue and improved nutrient absorption.

Experiment 2.

In this experiment, no additive effect of Zn and carbadox was found (Table 4). Carbadox had no effect on ADG, ADFI and ADFI/ADG during Phase 1, Phase 2 or the overall experiment. This contrasts with results from previously reported studies. On the other hand, Zn increased ADFI in both the first and second phases and the overall experiment. Although the increase in ADG as Zn concentration increased was not statistically significant in this experiment, supplementation with 1,500 and 3,000 mg/kg of Zn increased ADG by 15 and 16 percent in phase 2, and by 12 and 14 percent in the overall experiment. The nonsignificant effect of Zn on ADG was probably because there were only two replications per treatment in this experiment. The results of the second experiment agree with the results of the first experiment. Feeding pharmacological concentrations of Zn stimulated voluntary feed intake and weight gain of pigs during the nursery phase.

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The Effects of Dietary Feather Meal Concentration on Performance and Carcass Characteristics of Barrows

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Jill M. Heemstra[1]

Summary and Implication

An experiment was conducted to determine the effect of dietary feather meal level, as well as whether or not start weight influenced feather meal effects in growth performance and carcass traits of barrows. Dietary feather meal additions tended to decrease the final body weight variation of barrows. Barrows fed diets containing 20 percent feather meal from 80 pounds to slaughter had decreased average daily gain, average daily feed intake, digestible lysine intake, energy intake, daily lean gain and backfat depth. Barrows fed diets containing 10 percent feather meal from 190 pounds to slaughter had decreased average daily gain, average daily feed intake, digestible lysine intake, energy intake and backfat depth. The reduction in daily lean gain appears to be caused by decreased digestible lysine intake. Overall, feather meal can be used to reduce barrows feed intake, however, the dietary digestible lysine content should be adjusted.

Introduction

As more producers adopt all-in-all-out (**AIAO**) systems, the growth potential difference between barrows and gilts becomes a concern. Typically, barrows eat more feed, grow faster and reach market weight 10 to 14 days before littermate gilts. Because barrows and gilts have similar protein growth potential in the finishing phase, barrows have fatter carcasses than gilts at the same live weight. Producers may be able to improve profitability if barrows growth rate can be modified to be similar to that of gilts. Improving carcass leanness of barrows is another potential profit opportunity. The greater backfat for barrows compared to gilts results in a lower price because the market systems use backfat as a predictor of carcass lean. Research has demonstrated that feather meal (a high-protein, low energy feed ingredient) reduces feed intake in finishing pigs. This article describes a experiment conducted to examine the optimum level and timing of dietary feather meal additions to barrow diets. The overall objective was to slow down the growth rate and to improve the carcass leanness of barrows.

Procedures

A pool of 224 crossbred, high lean gain potential feeder pigs (196 barrows and 28 gilts) were purchased from a single source. At arrival, all pigs were weighed, eartagged and assigned randomly to experimental treatments on the basis of four weight outcome groups. Within outcome group, barrows were randomly assigned to one of seven treatment groups and gilts were assigned to control gilt group.

The experiment was conducted at the University of Nebraska Haskell Agriculture Laboratory at Concord. The facility is a fully slatted, double-wide, naturally ventilated barn with fresh water under-slat flushing for manure

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removal. One nipple drinker and two feeder spaces were provided in each 7 ft x 8 ft pen with a total of four pens per treatment combination. There were seven pigs in each pen with floor space of 8 ft^2/pig.

The control barrows (**CB**) and gilts (**CG**) were fed diets containing no feather meal from purchase to slaughter (Tables 1, 2 and 3). Treatment groups were two levels of dietary feather meal (**FM**, 10 and 20 percent), fed from three different starting weights (**SW**, 80, 135 and 190 pounds). Barrows were fed the same corn-soybean meal diets as the CB group before they reached the assigned starting weights, 80, 135 and 190 pounds. The CB group served as a benchmark to evaluate treatment effects. The CG group served as a benchmark to evaluate the performance of barrows.

Diets were formulated to contain similar metabolizable energy densities and the digestible lysine (the first limiting amino acid) concentrations used were derived from the Nebraska and South Dakota Swine Nutrition Guide. All pigs were fed a common corn-soybean meal diet formulated to contain 1 percent lysine from arrival until 80 pounds. Diets were switched on the week pigs weighed 80, 135 and 190 pounds. Pens of pigs were slaughtered the week the average pen weight was 240 pounds or greater.

Carcass lean was measured on individual pigs at slaughter using total body electrical conductivity (TOBEC) at SiouxPreme Packing Co., Sioux Center, Iowa. Backfat depth was measured at the tenth rib 2 inches off the midline by Renco LeanMeter five days prior to slaughter. Lean percentage was calculated on a 5 percent fat basis.

Table 1. Composition of diets from 80 to 135 pounds (as-fed basis).

	Diets[a]			
Ingredient, percent	CG	CB	FM 10-80	FM 20-80
Corn	71.80	73.85	63.95	54.25
Soybean meal, 44% CP	25.75	23.65	21.30	18.90
Feathermeal	——	——	10.00	20.00
Tallow	——	——	2.30	4.55
Premix[b]	2.45	2.50	2.45	2.30
Formulated composition[c]				
CP, %	17.40	16.60	23.30	29.90
Ca, %	.65	.65	.66	.65
P, %	.55	.55	.55	.55
ME, Mcal/lb	1.49	1.49	1.49	1.49
Amino acids, %				
Lysine	.93(.75)[d]	.88(.71)	.95(.71)	1.02(.71)
Tryptophan	.21(.16)	.20(.15)	.23(.16)	.26(.18)
Threonine	.67(.49)	.64(.46)	.93(.66)	1.20(.87)
Methionine+Cystine	.61(.50)	.59(.48)	.90(.68)	1.21(.88)
Analyzed composition				
CP, %	16.80	16.50	22.80	28.40
Ca, %	.68	.58	.69	.62
P, %	.53	.53	.51	.50
GE, Mcal/lb	1.75	1.78	1.88	2.11

[a]CG=control gilts; CB=control barrows; FM=feathermeal level and 80 is the starting weight, lb.
[b]The premix contained limestone, dicalcium, salt, vitamin, and mineral premixes.
[c]CP=crude protein; Ca=calcium; P=phosphorus; ME=metabolizable energy; GE=gross energy; DM=dry matter.
[d]The values in parentheses present apparent digestible amino acid percentage in the diet.

Table 2. Composition of diets from 135 to 190 pounds (as-fed basis).

	Diets[a]			
Ingredient, percent	CG	CB	FM 10-80	FM 20-80
Corn	74.10	79.70	69.85	60.05
Soybean meal, 44% CP	23.65	18.00	15.60	13.25
Feathermeal	——	——	10.00	20.00
Tallow	——	——	2.30	4.55
Premix[b]	2.25	2.30	2.25	2.15
Formulated composition[c]				
CP, %	16.60	14.60	21.20	27.90
Ca, %	.60	.60	.60	.60
P, %	.50	.50	.50	.50
ME, Mcal/lb	1.50	1.50	1.50	1.50
Amino acids, %				
Lysine	.88(.71)[d]	.73(.58)	.84(.58)	.91(.58)
Tryptophan	.20(.15)	.17(.12)	.20(.14)	.23(.15)
Threonine	.64(.46)	.56(.40)	.85(.60)	1.14(.81)
Methionine+Cystine	.59(.48)	.56(.44)	.85(.64)	1.15(.84)
Analyzed composition				
CP, %	16.60	14.90	21.40	27.40
Ca, %	.75	.50	.62	.65
P, %	.43	.48	.50	.42
GE, Mcal/lb	1.76	1.77	1.88	2.01

[a]CG=control gilts; CB=control barrows; FM=feathermeal level and 135 is the starting weight, lb.
[b]The premix contained limestone, dicalcium, salt, vitamin, and mineral premixes.
[c]CP=crude protein; Ca=calcium; P=phosphorus; ME=metabolizable energy; GE=gross energy; DM=dry matter.
[c]The values in parentheses present apparent digestible amino acid percentage in the diet.

Results and Discussion

The coefficient of variation of final weights is an expression of the body weight variation within each pen at time of slaughter. Barrows fed 10 percent FM from 190 pounds and 20 percent FM from 135 pounds tended ($P < .1$) to have smaller coefficient of variations at the end of the experiment (Table 4). This observation suggests dietary FM could be used to reduce the final body weight variation of barrows.

The CB group had the greatest average daily gain (Table 4). Barrows fed 20 percent beginning at 80 pounds had reduced (P 05) ADG than control groups. Barrows fed 10 percent FM from 190 pounds and 20 percent FM from 80 pounds had slower

Table 3. Composition of diets from 190 to slaughter (as-fed basis).

	Diets[a]			
Ingredient, percent	CG	CB	FM 10-190	FM 20-190
Corn	81.40	84.55	74.50	64.75
Soybean meal, 44% CP	16.50	13.25	11.10	8.70
Feathermeal	——	——	10.00	20.00
Tallow	——	——	2.30	4.55
Premix[b]	2.10	2.20	2.10	2.00
Formulated composition[c]				
CP, %	14.10	13.00	19.70	26.30
Ca, %	.55	.55	.55	.55
P, %	.45	.45	.45	.45
ME, Mcal/lb	.50	1.51	1.51	1.51
Amino acids,%				
Lysine	.69(.54)[d]	.60(.47)	.68(.47)	.75(.47)
Tryptophan	.16(.12)	.14(.10)	.17(.12)	.20(.13)
Threonine	.54(.38)	.49(.35)	.79(.55)	1.00(.76)
Methionine+Cystine	.53(.43)	.50(.40)	.80(.60)	1.11(.80)
Analyzed composition				
CP, %	14.80	12.40	18.90	25.20
Ca, %	.55	.62	.59	.59
P, %	.48	.40	.40	.36
GE, Mcal/lb	1.77	1.75	1.86	2.01

[a]CG=control gilts; CB=control barrows; FM=feathermeal level and 190 is the starting weight, lb.
[b]The premix contained limestone, dicalcium, salt, vitamin, and mineral premixes.
[c]CP=crude protein; Ca=calcium; P=phosphorus; ME=metabolizable energy; GE=gross energy; DM=dry matter.
[d]The values in parentheses present apparent digestible amino acid percentage in the diet.

(P < .05) average daily gains than control harrows and their average daily gain was similar to CG. The control gilts had the lowest average feed intake among all treatment groups, and harrows fed 20 percent FM from 80 pounds had similar feed intake as CG. Barrows fed 10 percent FM from 190 pounds and 20 percent FM from 80 pounds consumed less (P 05) feed than control barrows. Feed efficiency was not affected by dietary FM additions.

The daily digestible lysine intake of CG and CB were greater (P < 05) than harrows fed 10 percent FM from 190 pounds and 20 percent FM from 80 pounds. Barrows fed 10 percent FM from 190 pounds and 20 percent FM from 80 pounds had less (P 05) daily metabolizable energy intake than the control harrows, with energy consumption similar to the control gilts. The control barrows and control gilts had similar daily lean gains. Twenty percent dietary FM fed from 80 pounds reduced (P < 05) the daily lean gain of harrows. Barrows fed 20 percent FM from 80 pounds had similar average daily gains and average daily feed intakes similar to control gilts. Pigs in this group needed seven additional days to reach market weight when compared to control harrows.

The control gilts had the least backfat and the control harrows had the greatest backfat depth among treatment groups. Barrows fed 10 percent FM from 190 pounds and 20 percent FM from 80 and 190 pounds had reduced (P < .05) backfat depth compared with control harrows. There was a significant effect of SW (P < .05) on backfat depth, suggesting that the timing of FM additions is more important than dietary concentration to reduce barrows backfat. In this study, barrows

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Table 4. Performance and carcass criteria of barrows and gilts.

Treatment[k]	CG	CB	10% FM			20% FM		
Item[e]			80	135	190	80	135	190
Initial wt., lb	59.2[a]	46.6[b]	46.5[b]	46.8[b]	46.8[b]	46.7[b]	46.6[b]	46.8[b]
Final wt., lb	249.4	256.3	259.3	260.5	249.0	251.8	256.9	248.4
Final C.V.[1]	6.8[xy]	9.1[x]	6.6[xy]	7.9[xy]	5.8[y]	8.6[xy]	6.2[y]	7.0[xy]
ADG, lb[g]	1.82[d]	2.01[a]	1.98[a]	1.98[a]	1.87[bcd]	1.84[cd]	1.95[ab]	1.93[abc]
ADFI, lb[g]	5.28[c]	5.76[a]	5.83[a]	5.78[a]	5.41[bc]	5.31[c]	5.60[ab]	5.59[ab]
Feed/Gain	2.90	2.87	2.94	2.92	2.89	2.89	2.87	2.90
DDLI, g/d[g]	15.8[a]	15.4[ab]	15.6[ab]	15.4[ab]	14.7[cd]	14.4[d]	15.2[bc]	15.2[bc]
EI, Mcal/d[g]	17.25[d]	18.84[ab]	19.05[a]	18.89[ab]	17.68[cd]	17.35[d]	18.30[abc]	18.27[bc]
DLG, lb/d[g]	.70[a]	.70[a]	.70[a]	.68[a]	.67[ab]	.63[b]	.66[ab]	.69[a]
Backfat, mm[h]	11.4[c]	15.7[a]	14.7[ab]	14.4[ab]	12.9[bc]	13.8[b]	14.8[ab]	13.5[b]
HC, lb	182.9[ab]	186.0[ab]	188.8[ab]	180.8[ab]	183.4[ab]	185.4[ab]	179.7[b]	
Lean %[ij]	51.51[a]	48.32[bc]	48.55[bc]	47.77[bc]	4908[b]	47.57[bc]	47.00[c]	48.53[bc]

[abcd]Means in the same row without a common superscript differ (P < .05).
[c]ADG=average daily gain; ADFI=average daily feed intake; HC=hot carcass weight; DLG=daily lean gain; DDLI=daily digestible lysine intake; EI=energy intake, metabolizable.
[f]Coefficient of variation of within pen weight at time of slaughter.
[g]FM x SW interaction (P < .05).
[h]Main effect of start weight (P < .05).
[i]Containing 5 percent fat.
[j]Main effect of start weight (P = .07).
[k]CG=control gilts; CB=control barrows; FM=feathermeal and 80, 135 and 190 are starting weights, lb.
[xy]Means in the same row without a common superscript differ (P < .1).

fed dietary FM (10 and 20 percent) from 190 pounds had a significant backfat reduction. None of the FM treatments reduced the backfat to the same depth as control gilts.

We acknowledge the lean percentage of these high lean gain pigs appears low. We checked the equation used in conjunction with TOBEC readings, and discussed the results with the packer, but did not find any reason to explain this observation. The lean percentage values in Table 4 are based on 5 percent added fat. They are surprisingly low, given the backfat measurements and visual appraisal at time of slaughter. The SW tended (P = .07) to affect the lean percentage. The control gilts had the highest lean percentage. Dietary FM did not improve the lean percentage of barrows to equal that of the control gilts in this study.

Barrows fed 20 percent FM from 80 pounds had similar average daily gain, average daily feed intake and energy intake as control gilts, but the daily lean gain and lean percentage were less than control gilts. An explanation for this situation is a reduction in daily digestible lysine intake. The reduction of digestible lysine intake may have limited the daily lean gain of the barrows. When compared to the barrows fed 10 percent FM from 190 pounds, the barrows fed 20 percent FM front 80 pounds had numerically more backfat and less carcass lean. This indicates that feeding 20 percent FM from 80 pounds may help manipulate the growth performance of barrows to resemble that of gilts, but the lean growth and carcass lean percentage will decrease if the dietary digestible lysine intake is not adjusted. These results suggest that feeding 10 percent FM during the late finishing phase and adjusting dietary digestible lysine concentration to meet the maximum lean growth requirement may slow daily gain and improve carcass leanness of barrows.

Conclusion

Feather meal reduces barrows average daily gain and average daily feed intake. The dietary digestible lysine content should be adjusted to meet the maximum lean growth if FM is used to slow growth rate and improve carcass leanness of barrows.

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Defining Swine Nutrient Requirements and Allowances—What do the Numbers Mean?

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Austin J. Lewis
Duane E. Reese
Michael C. Brumm[1]

Summary and Implications

Defining nutrient requirements or allowances is the first, and conceivably most important step, in developing a nutrition program for growing-finishing pigs. Understanding the terminology and underlying principles used to define nutrient requirements and allowances for pigs will help producers better evaluate their nutrition programs. This information will also enable producers to interface production outputs (e.g., growth rate and carcass data) to published nutrient requirement and allowance programs, such as The National Research Council, Nutrient Requirements of Swine, 1998. As these and other approaches describing nutrient requirements for pigs develop, producers need a better and more complete understanding of growth biology in order to help them accurately determine the nutritional needs of their pigs. Because of the diminishing-return response of growth and biological traits to nutrient intake or concentration, the added costs associated with increasing nutrient densities at or near the requirement must be carefully considered.

Introduction

Nutrient requirements/allowances are determined based on the response of biological or growth criteria to varying intakes or concentrations. These criteria vary according to the physiological state of the pig (i.e., growth, pregnancy or lactation) and the level of production (e.g., 1.5 versus 2.2 pounds weight gain/day). The objectives of this article are to review the general processes for development of nutrient requirements and allowances, to illustrate the differences between a nutrient requirement and allowance, and to discuss how maximizing a biological response may not maximize economic returns.

Performance Criteria

Nutrient requirements are rarely based on a single research experiment but most often derived from a variety of experiments. Conditions vary among

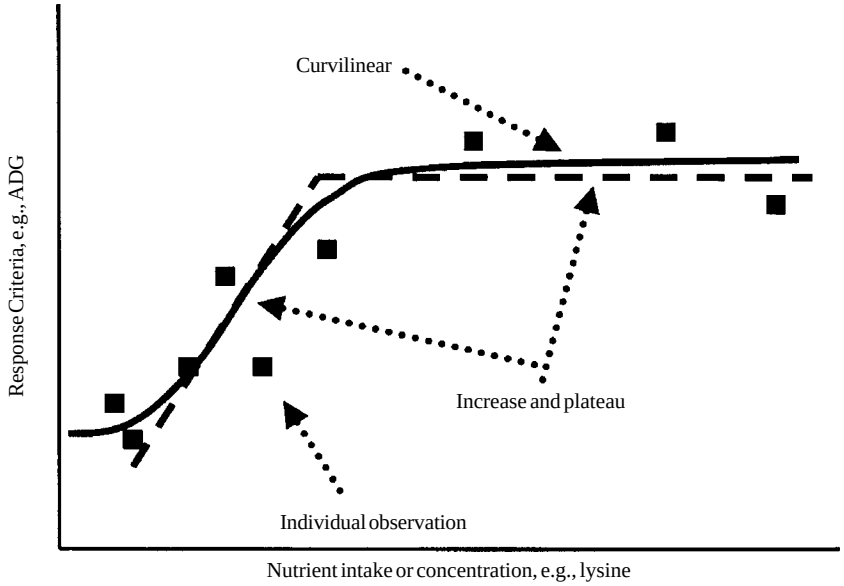

Figure 1. The response of growth to nutrient intake or concentration.

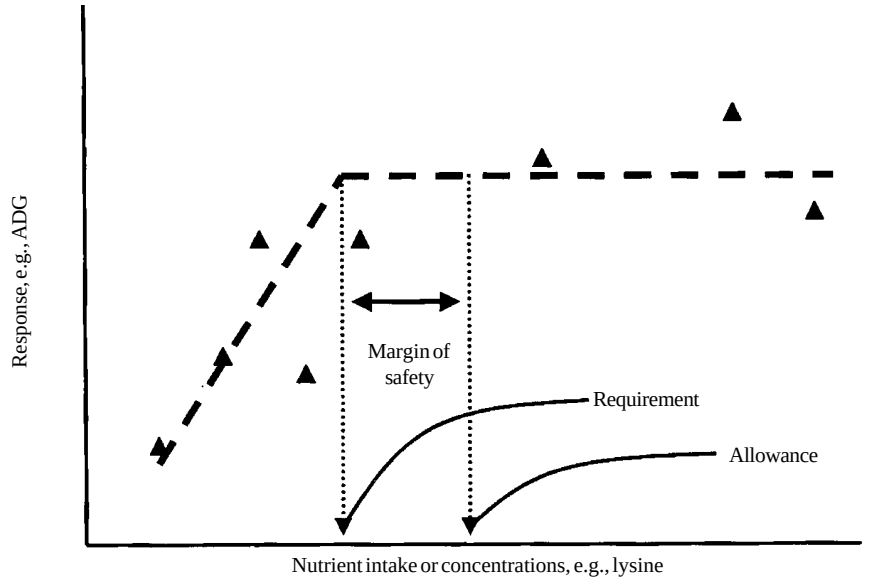

Figure 2. Representation of a nutrient requirement and allowance.

experiments or the production systems used to develop nutrient requirements and allowances. These conditions must be considered when determining a requirement or allowance's applicability. To establish a requirement or allowance, a production and/or biological criterion must be identified. Also, the criterion selected must vary (increase or decrease) according to the concentration of the nutrient of interest.

A common growth trait used to establish requirements or allowances for growing-finishing pigs is average daily gain (ADG). The response of ADG to nutrient (e.g., lysine) intake is curvilinear (increases linearly and reaches a plateau after the requirement has been observed, see Figure 1). Often, the response of the performance trait is represented by two linear lines (increase and plateau).

Nutrient Requirements Versus Allowances

Depending on the source or publication, either nutrient requirements or allowances will be presented. **A requirement is defined as the nutrient intake or concentration that maximizes the response criteria. An allowance is equivalent to the requirement plus an additional amount often called a margin of safety** (see Figure 2). The new National Research Council publication documenting swine nutrient needs is requirement-based (NRC, 1998, Tenth Revision, National Academy Press, Washington, D.C.), whereas the Nebraska and South Dakota Swine Nutrition Guide (Nebraska Cooperative Extension Publication 95-210) presents nutrient allowances. Generally, using nutrient allowances to formulate diets eliminates the possibility of under feeding a nutrient, a scenario more likely using nutrient requirements. The downside of using allowances is the potential for overfeeding a nutrient, which in the case of expensive ingredients, increases costs and decreases profit. In addition, dietary nutrient excesses will increase nutrient excretion, contributing to environmental problems.

Underlying Biological Processes

While performance criteria are useful in defining nutrient specifications, describing and measuring the underlying biological process(es) utilizing the nutrient are helpful in establishing the nutrient requirement. An example of this is in the NRC, 1998 *Nutrient Requirements of Swine*. In this publication, the driving force defining the lysine (and other dietary essential amino acids) requirements for growing-finishing pigs is the rate of muscle protein deposition, or simply, the rate of lean deposition (see Figure 3). The shape of the curve is assumed constant (unless indicated differently by the user) and is adjusted according to the average daily lean gain estimated by the user. If the

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Figure 3. The lean growth curve of a growing-finishing pig.

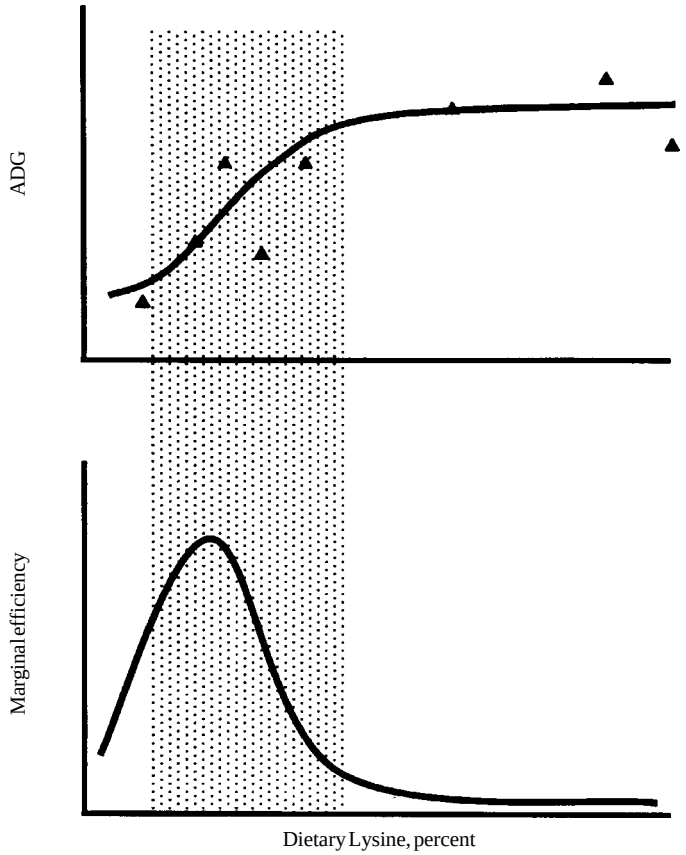

Figure 4. The relationship between average daily gain and the efficiency with which lysine is used for growth.

concentration of lysine in muscle protein is known and the proportion of dietary lysine absorbed and metabolized (not degraded or used for non-muscle functions) is estimated, the amount of dietary lysine required can be determined. Therefore, producers can utilize kill-sheet information listing the lean (muscle) percentage in their pigs, along with an estimate of initial lean percentage (estimated from the initial weight of pigs entering the growing-finishing facility), to apply to the model of lysine utilization developed by the NRC and estimate the lysine requirement.

Maximizing Growth versus Maximizing Profit

Because the response of growth traits follows a pattern of diminishing returns (see Figure 1), maximizing the response does not always define a nutrient concentration or intake that will maximize profit. As the requirement is approached, the efficiency (marginal efficiency) of utilizing the nutrient for a specific function (e.g., lean growth) decreases dramatically (Figure 4). Depending on the nutrient in question, the additional cost of increasing the concentration of a nutrient in the diet to increase growth or performance from 95 to 100 percent of maximum may be greater than the potential return. Studies at the University of Wisconsin demonstrated that formulating diets to maximize growth by adding supplemental dietary lysine can add as much as $2.76/pig to the cost of producing a 240-pound pig with no or little benefit in growth rate and/or carcass quality.

Because producers must consider the diminishing return response, dietary nutrient intakes or concentrations should be scrutinized to ensure the nutrient is not being overfed relative to the potential economic return.

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Response to Increasing Levels of Nutrients Fed During Gestation and Lactation to Control and Prolific Gilts

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Summary and Implications

Normal diets and diets with 50 percent greater amounts of protein, vitamins and certain minerals were fed during the gilt development period through lactation to gilts of lines that differed in litter size. The lines had been developed with 10 generations of genetic selection that resulted in a difference between the prolific line and a randomly selected control line of 2.9 fully formed pigs at birth in first parity sows. However, the large litter size line also had greater numbers of stillborn pigs, smaller pigs at birth and greater pre-weaning mortality. The purpose of the experiment was to determine whether these losses in the prolific line could be reduced by feeding diets with greater density of all nutrients except energy during the period of gilt development through completion of the first lactation. The diet fed during gilt development and gestation did not affect total number of pigs born per litter or the number born alive. However, there was an increase of .9 pigs born alive (P=.07) in litters of the selected line when the high nutrient diet was provided. The increase in number born alive in the selected line was not significant at the .05 probability level customarily used for significance, but is close enough to indicate nutrient requirements for maximum productivity is greater for prolific gilts than for gilts with average litter sizes. The development/gestation feeding regimen did not affect pig birth weights, so the greater number of live pigs in litters of prolific sows was not due to heavier pigs. Litter sizes were standardized at birth so variation in number born would not affect litter weaning traits. There was no difference in number weaned due to line, development/gestation diet or lactation diet. However, pig weaning weights were 95 pounds greater (P<.050) when the dam had received the high-nutrient diet during gestation. The carryover effect of the high-nutrient gestation diet was to significantly increase feed intake during lactation, which probably increased milk production and caused heavier pig weaning weights. In addition, weaning weights of pigs were .57 pounds greater (P<.05) when nursed by sows fed the high-nutrient diet during lactation, even though the sows did not consume more lactation feed than sows fed the normal diet. There were no interactions among lines and diets for traits measured at weaning. Genetic selection can increase litter size. Very prolific females may have greater nutrient requirements for maximum reproductive performance than sows with average litter sizes. Pig weaning weights can be increased by feeding more nutrient-dense diets from the gilt development period through the first lactation.

Introduction

Increasing litter size weaned improves the economic efficiency of pork production. However, as litter size at birth is increased through genetic selection, the number of stillborn and mummified piglets also increases and pig birth weights decrease. Low birth weights are a major cause of pig deaths within the first three days postpartum. Because of this, increased litter size at birth may not increase numbers weaned per litter.

In part, differences between large and small fetuses within litter at late gestation may be due to nutrient intakes during gestation. Nutrient concentrations in gestation diets designed for females with average litter sizes may be inadequate for lines with large litter sizes. However, in studies investigating the effects of nutrition on reproduction in which the amount or concentration of only one nutrient in gestation or lactation diets was increased, there was little increase in either numbers born or numbers weaned per litter. Therefore, if nutrition is a limiting factor to prenatal and postnatal survival in large litters, the smaller fetuses in large litters probably do not suffer from the lack of only one nutrient, but from a combination of several nutrients.

The objective of this study was to determine responses in sow and litter traits of a line selected to be prolific and a control line to diets with increased levels of nutrients fed during gestation and lactation.

Material and Methods

For the study, 2 16 Landrace-Large White crossbred gilts from the eleventh generation of three genetic lines were used. One line had been selected on an index of ovulation rate and embryonic survival, another on testes weight and the third was a randomly selected control. Because selection for testis size did not change litter size compared to the control line, the testes line was included to give additional numbers to the control line. Although the testes size and control lines did not differ in litter size, the testis size line had greater growth rate from weaning to 230 pounds and was fatter. Thus, gilts were considered as representing three lines in experimental design and data analyses. The average litter size

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born in the tenth generation was 12.6 pigs for the index line and 9.5 pigs for the control and testes lines.

Females were randomly assigned to two gestation and two lactation diets in a 3x2x2 factorial design. The diets were a high-nutrient gestation and a high-nutrient lactation diet and the normal gestation and lactation diets fed at the University of Nebraska swine unit. All nutrients, except salt and selenium, were increased by approximately 50 percent in the high-nutrient gestation and lactation diets (Table 1). Dietary energy density was not increased, as observations show gilts on the normal diet maintained good condition throughout gestation, so energy was not thought to be a limiting factor. Also, other studies showed increasing the amount of energy fed during certain periods of gestation could decrease litter size at birth. Previous studies at Nebraska indicated excessive energy intake during gestation significantly reduced feed intake during lactation. Different nutrient levels in diets were obtained by varying the amounts of corn, soybean meal (44 percent CP), dicalcium phosphate and a mineral/vitamin premix.

Gestation diets were fed for a minimum of 30 days before breeding and throughout gestation. Gilts were group-fed with 10 gilts per pen during development and breeding. An average of 4.5 pounds of feed per gilt per day was fed during development and an average of 6 pounds of feed per gilt per day was fed during the breeding period until mating. After mating, gilts were fed 4.5 pounds per day. During gestation, gilts were fed individually 4.5 pounds of feed per day until 85 days of gestation and 8 pounds per day thereafter. Gilts were individually fed twice per day during lactation and were provided all the feed they would consume.

Gilt weight and backfat thickness were measured at breeding, farrowing and weaning. Litter size and individual pig weights were recorded at birth and weaning. Cross-fostering within and between lines was used within two days of birth to standardize litter sizes to approximately 10 pigs per gilt. Pigs were weaned at approximately 28 days. Feed intake for each gilt was also recorded during lactation.

Table 1. Nutrient composition of gestation and lactation diets (as-fed basis)[a,b,c]

Nutrient	GC	GH	LC	LH
ME, kcal/lb[a]	1408	1379	1546	1517
CP,%[a]	11.6	18.1	13.6	21.0
Lysine, %	.51	1.00	.66	1.22
Calcium, %	.90	1.24	.91	1.24
Phosphorous, %	.85	.97	.87	.98
Zinc, ppm	110.2	165.3	110.2	165.3
Iron, ppm	110.2	165.3	110.2	165.3
Copper, ppm	11.02	16.53	11.02	16.53
Iodine, ppm	.22	.33	.22	.33
Manganese, ppm	22.05	33.07	22.05	33.07
Sulfur, ppm	66.14	102.5	66.14	102.5
Aluminum, ppm	2.57	3.82	2.57	3.82
Selenium, ppm	.30	.30	.30	.30
Vitamin A, IU/lb	2500	3750	2500	3750
Vitamin E, IU/lb	12.50	18.75	12.50	18.75
Folic acid, ppm	2.20	3.31	2.20	3.31
Riboflavin, ppm	5.51	8.27	5.51	8.27
Pantothenic Acid, ppm	22.05	33.07	22.05	33.07
Vitamin B_{12}, ppm	.02	.03	.02	.03
Choline, ppm	551.2	826.7	551.2	826.7
Biotin, ppm	.11	.17	.11	.17
Vitamin D_3, IU/lb	250	375	250	375
Vitamin K, ppm of menadione	3.31	4.96	3.31	4.96
Niacin, ppm	33.07	49.60	33.07	49.60
Ethoxyquin, ppm	1000	1500	1000	1500

[a]ME = metabolizable energy and CP = crude protein.
[b]GC = normal gestation diet, H = high-nutrient gestation diet, LC = normal lactation diet and LH = high-nutrient lactation diet.
[c]Values for trace minerals and vitamins represent added quantities to the diet.

Table 2. Mean values for litter traits[a] and gilt traits[b] measured at breeding and farrowing.

Diet[c]	Line[d]	N	FULLYF	NBA	MUMM	BWT, lb	BFBR, in	WTBR, lb	BFFAR, in	WTFAR, lb
GC	C	32	10.8	9.7	.25	2.51	0.99	263.9	1.14	378.1
	I	61	11.5	9.6	.54	2.36	1.02	270.7	1.23	382.7
	T	18	8.9	8.3	.61	2.71	1.08	272.3	1.30	399.9
GH	C	30	9.5	9.1	.13	2.60	0.95	261.5	1.15	379.0
	I	58	11.9	10.5	.72	2.31	0.99	268.1	1.15	384.0
	T	17	8.1	7.6	.24	2.62	1.01	256.0	1.22	375.2
Diet GH - Diet GC			-.6 NS	-.1 NS	-.1 NS	-.02 NS	-.05	-7.1 NS	-.05 *	-7.5 NS

[a]FULLYF = number of fully-formed piglets born, NBA = number of piglets born alive, MUMM = number of mummified fetuses and BWT = individual birth weight.
[b]BFBR = average backfat at breeding, WTBR = gilt weight at breeding, BFFAR = average backfat at farrowing and WTFAR = gilt weight at farrowing.
[c]GC = control diet fed during development and gestation and GH = high-nutrient diet fed during development and gestation.
[d]C = control line, I = index line and T= testes line.
*P<.05

Table 3. Mean values for litter traits[a] and gilt traits[b] measured at weaning.

Diet[c]	Line[d]	N	NW	WNWT, lb	BFWN, in	WTWN, lb	FDINTK, lb
GC LC	C	15	9.2	12.21	0.89	273.1	165.3
	I	25	8.1	12.79	0.94	281.3	180.1
	T	11	8.1	11.93	1.09	294.1	164.2
GC LH	C	12	8.8	13.60	0.94	313.9	201.7
	I	26	8.6	13.27	0.94	313.9	194.4
	T	6	8.7	11.20	1.04	295.0	116.4
GH LC	C	12	8.5	13.07	1.02	313.5	196.7
	I	27	8.4	12.92	0.90	300.5	212.5
	T	6	8.8	13.23	1.14	308.0	225.5
GH LH	C	14	8.9	14.79	0.84	310.0	222.0
	I	22	8.9	12.96	0.87	304.5	207.2
	T	10	8.3	13.78	1.01	320.3	203.5
Diet GH - Diet GC			.1 NS	.95 **	-.01 NS	14.3 NS	41.0 **
Diet LH - Diet LC			.2 NS	.57 **	-.06 NS	14.6 NS	.2 NS

[a]NW = number of pigs weaned and WNWT = individual piglet weaning weight.
[b]BFWN = average backfat at weaning, WTWN = gilt weight at weaning and FDINTK = amount of feed consumed during lactation.
[c]GC = control diet fed during development and gestation, GH = high-nutrient diet fed during development and gestation, LC = control diet fed during lactation and LH = high-nutrient diet fed during lactation.
[d]C = control line, I = index line and T = testes line.
**P<.01

Statistical analyses were conducted to estimate effects of gestation and lactation diets, and interaction of diets with each other and with genetic lines.

Results

Number of fully-formed piglets born, number of piglets born alive and number of mummified fetuses were not significantly affected by gestation diet (Table 2). These traits were significantly different between lines, but line x diet interactions were not significant. The index line had the largest litters and number of mummified fetuses. Index line gilts receiving the high-nutrient gestation diet had .9 more live piglets born (P=.07), whereas the high-nutrient diet did not significantly increase number of pigs born alive in the control and testes size lines. This line x diet interaction approached significance (P=.12). The number of stillborn piglets was reduced in the index line by a 50 percent increase in dietary nutrient density. This response in litter size occurred only in the index line. Because the probability value for significance was .07, there is not strong evidence that the nutritional needs for maximum litter size of gilts of the prolific and control lines are different. However, the data are consistent with the hypothesis that the nutritional needs of the highly prolific gilts were not met with the control diet and that increasing the amount of nutrients fed during development and gestation has the potential to increase litter size in highly prolific females.

Individual pig birth weights were not significantly affected by gestation diet (Table 2). However, lines differed (P<.05) as index line piglets were smallest at birth whereas testes line piglets were largest. There was a statistically significant line x diet interaction on individual pig birth weights. But the interaction was the opposite of what was expected and does not explain the increased number of live pigs at birth in litters by index gilts when they were fed the high-nutrient gestation diet. Control line piglets from mothers fed the high-nutrient diet during gestation were .09 pounds heavier than control line piglets from mothers fed the control diet during gestation. However, the high-nutrient diet fed during gestation decreased individual birth weights in the index line by .05 pounds and by .09 pounds in the testes size line.

Number of pigs weaned was not significantly affected by gestation diet, lactation diet or line (Table 3), and interactions between diets and lines were not significant. Individual weaning weights were increased by .95 pounds (P<.05) when pigs were nursed by gilts fed the high-nutrient diet during development and gestation, suggesting a carry-over effect of gestation diets on milk production and pig growth during the lactation period (Table 3). This increase in weaning weight likely occurred because of greater milk production caused by greater feed intake during lactation. Regardless of the diet fed during lactation, gilts fed the high-nutrient diet during development/gestation consumed more feed during lactation. The high-nutrient lactation diet also increased weaning weights by .57 pounds (P<.05). Pig weaning weights also differed significantly among lines. Control line females weaned the heaviest pigs, whereas testes line females weaned the lightest pigs. Increasing levels of nutrients fed during gestation had the effect of increasing pig weaning weights in the control line by 1.04 pounds and by 1.90 pounds in the testes size, but did not affect weaning weights in the prolific line. This interaction was significant. High levels of nutrients fed during lactation increased pig weaning weights in all lines, but pig weaning weights were increased more in the control line (1.54 pounds) than the testes line (.37 pounds) and index line (.26 pounds). Again, this interaction was significant. The effect on pig weaning weights of increasing nutrient density of lactation diets may be different for gilts of prolific lines and those with more average litter sizes.

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Are The Sows Fed Adequately?

Duane E. Reese[1]

Summary and Implications

Feeding and managing sows so changes in their body weight and condition fall within predetermined targets is critical for successful reproduction. General feeding recommendations are useful in designing a feeding strategy for sows in all pork producing operations. However, nutrient requirements are not the same for all sows and there are differences in how well producers implement feeding protocols. It is important sows be monitored systemically on farms to ensure their nutrient requirements are met. Body condition scoring seems to be the most practical and useful method of monitoring sows compared to backfat probing or weighing. Guidelines on how to condition score sows, as well as how to adjust feed intake to achieve a desired body condition score, are provided.

Introduction

The importance of managing sows so they do not gain or lose too much weight or body condition during each parity is well-established. Farrowing difficulties, poor rebreeding performance and high culling rates are frequently due to inadequate control of sow body weight and condition. In addition, the direct economic consequences of under- or overfeeding sows on annual feed costs can be substantial. For example, providing a herd of 500 gestating sows an extra .5 pounds/day of a feed that costs $135/ton will increase annual feed cost by at least $4,000. This estimate does not include the cost to provide the heavier sows with more feed just to meet their maintenance requirement. Because an increasing number of sows are being fed and housed individually, it is possible to feed sows according to individual need.

General sow feeding recommendations are available from universities, veterinarians, private consultants and feed industry representatives. However, because there is variation in animals, environmental conditions and job performance of people, those recommendations may not be directly applicable to some pork production units. Therefore, it is necessary to monitor sows on individual farms to determine the adequacy of the current feeding management practices. There are at least three methods to assess how well sows are being fed: body condition scoring, backfat probing and weighing. In the following paper, the scientific merit and practical significance of these methods will be discussed.

Research Results

Body condition scoring

Most producers who body condition score visually inspect the sow's body around the region of the backbone and hips and then decide how much feed she needs to achieve a target condition score at farrowing. A few producers will also palpate the sow's hips and ribs to estimate backfat thickness. Body condition scoring is the most popular of the three methods, because no equipment is required and it requires less time. However, condition scoring is very subjective, and can result in misjudging and incorrect feeding.

Studies indicate condition scoring does not reliably estimate the amount of backfat or bodyfat sows have (r^2 = .09 to .53). In addition, other studies found no relationship between body condition score and rebreeding performance in sows. As expected, the reproducibility of condition scores (the extent to which independent evaluators agree on the score of sows) is about 15 percent less than when using objective methods such as electronic backfat probing.

Backfat probing (electronic)

Usually, researchers and producers determine a sow's backfat by electronically probing the tenth rib area just off the midline. Because an electronic probe provides a more objective evaluation of body condition than condition scoring, it is a valuable tool for teaching people how to condition score. However, backfat probing is more time consuming than body condition scoring and requires an investment in a probe. A few producers are using a backfat probe on sows.

Research results show the amount of backfat a sow has at weaning is not a reliable predictor of rebreeding performance. Although a backfat probe will provide a reliable estimate of a sow's body fat content, most research indicates the amount of body protein is a bigger factor affecting rebreeding performance than body fat level.

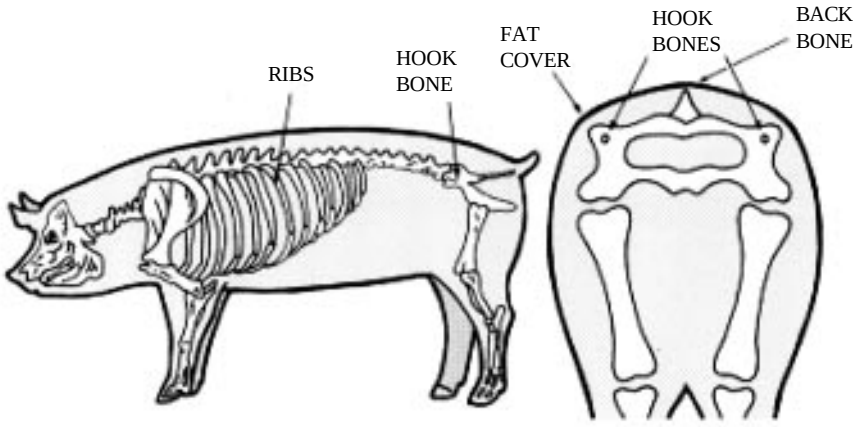
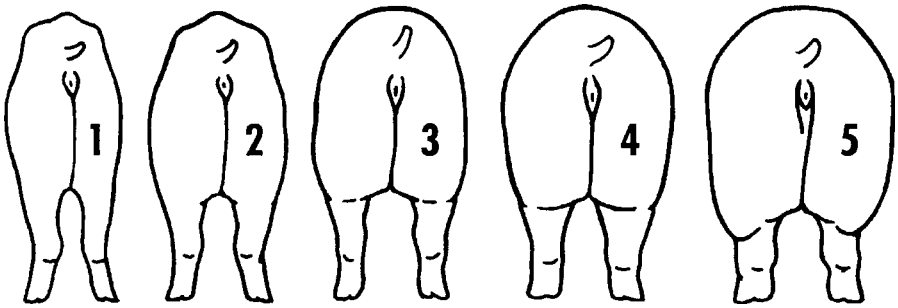


Figure 1. Location of the ribs, backbone and hook "H" bones of the sows.



Score	Condition	Detection of ribs, H-bones and backbone
1	Emaciated	Obvious
2	Thin	Easily detected with palpation
3	Ideal	Barely felt with firm palm pressure
4	Fat	None
5	Overfat	None

Figure 2. Condition scores of sows (adapted from Patience et al., 1995).

Weighing

While weighing provides objective information, it is time consuming, requires an investment in scales and many producers do not have the facilities to weigh sows efficiently. In contrast to backfat probing, weighing accounts for the total tissue mass of the sow's body. However, research indicates body weight and backfat are poorly correlated (r = .20 to .53), indicating some sows get fatter as they gain weight from one parity to the next and others loose backfat but still gain weight.

It is generally accepted that sows in normal condition and housed under reasonable environmental conditions (in confinement at 65°F), should gain between about 75 and 110 pounds during pregnancy (Table 1). If sows are fed to achieve these gains, they should perform adequately.

Table 1. Suggested target weight gains during successive pregnancies of high-producing sows[a].

Parity	Littersize, total	Maternal weight gain, lb	Conceptus weight gain, lb[b]	Total weight gain, lb[c]
1	10.0	60	50	110
2	11.0	50	55	105
3	12.0	45	60	105
4	12.0	40	60	100
5	12.0	30	60	90
6	11.0	20	55	75

[a]Adapted from Aherne and Williams, 1992 and Verstegen et al., 1987.
[b]Conceptus (placental membranes, fluids, and the fetus) assumed to weigh 5 lb/fetus (NRC 1998).
[c]Maternal + conceptus weight gain.

Best Method

All three methods have limitations. When considering the overall value of the results and cost to the producer, however, condition scoring seems to be the best way to access how well sows are fed and managed on individual farms. Although condition scoring is not useful for estimating the amount of backfat on individual sows, it is valuable for assessing the relative degree of conditioning in a group of sows. An evaluator who correctly condition scores evaluates both backfat thickness and lean body mass, both essential tissues for sustained reproduction. Backfat probing by itself is not very useful, but it could be if it were combined with a measure of muscle mass. To increase the usefulness of weighing sows, also estimate backfat, either by palpation or electronic probe.

How to Condition Score

For best results with condition scoring, locate the ribs, backbone and hook "H" bones of the sow (Figure 1). Palpate the ribs and the "H" bones to access fat cover. Observe the backbone's prominence and give the sow a score between "1" and "5" (Figure 2). A sow should attain a score of "3" just before farrowing. In general, if it takes more than 3 seconds to feel the ribs or "H" bone on a sow, she is probably a "4" or "5". Obviously, it is much easier to condition score and feed sows according to need if they are housed in individual stalls rather than in pens.

In general, it is best to condition

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score each sow three or four times during each gestation in herds with reproductive problems or in herds with no history of recorded condition scoring. Once sow body condition in a herd stabilizes to a desired level or a feeding management protocol is proven satisfactory, a condition score monitoring program is probably sufficient. In a monitoring program only 15 to 20 percent of the sow groups are actually condition scored as described above.

Try combining condition scoring with other activities, such as pregnancy checks and vaccinations, to save time opening gates and positioning people to score sows. Good times to score would be at mating, and at about day 50 and 90 of gestation. Results are more accurate if the scores of two people are averaged. The same "team" should be delegated the responsibility to condition score if possible. It is also important to note the sow's condition score on her information card, otherwise monitoring her progress is impossible. One convenient way to record an individual sow's score would be to include the information shown in Figure 3 on the sow's card and simply check or circle the drawing best representing the score given at evaluation.

The process of body condition scoring described in this paper might seem labor-intensive compared to other methods. The objective of any efforts to determine the adequacy of a sow feeding program should be to collect valid data to use to make sound management decisions. Some operations would make better use of human resources and have more useful data by reducing the number of times sows are "condition scored" and implement the above procedure.

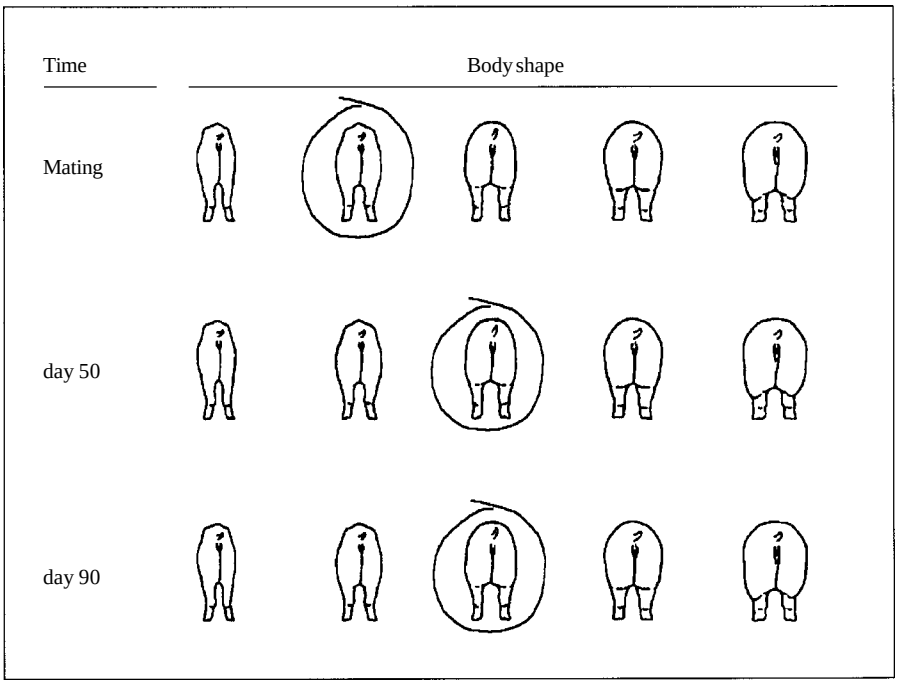

Figure 3. Example record of condition scores on one sow during gestation.

Adjusting the Feed

It is important to define an operation's "base feeding rate" in order to use body condition scoring effectively. A base feeding rate represents that amount of feed which will allow a sow to gain the proper amount of weight and condition during gestation, assuming she is housed in an environmentally regulated facility and has a body condition score of about 2.5 at mating. In most operations, the base feeding rate is 4 to 4.5 pounds per day of a corn or milo-soybean meal diet during gestation.

Some sows loose considerable weight and condition during lactation, resulting in a body condition score less than 2.5 at mating. These sows need to be given more feed than the base amount, because they need to exceed the maternal weight gains shown in Table 1. Other sows may be over-conditioned at mating and should be fed less than the base amount of feed to gain slightly less weight than shown in Table 1.

How should the feed adjustments be determined? According to the 1998 National Research Council's model on the nutrient requirements of swine, maternal weight gain during gestation changes by about 20 pounds for each one-half pound of a corn/soybean meal diet (metabolizable energy = 1,450 kcal/pound) that is given above or below a base amount of feed (4 to 4.5 pounds/day; Table 2). Thus, if a second parity sow needed to gain 70 pounds of maternal weight during gestation instead of 50 pounds (normal weight gain, Table 1), she should be fed the base amount of feed plus 5 pounds of feed/day during gestation (total of 4.5 to 5.0 pounds feed/day).

Table 2. Effect of .5 pound/day adjustments in sow gestation feed intake relative to a base amount on maternal weight gain change during gestation[a,b].

Deviation from base feed amount, lb/d[c]	Maternal weight gain change, lb
-.5	-20
0	0
.5	20
1.0	40

[a] A 350 to 450 lb sow housed in an environmental regulated facility at 65°F for 115 days.
[b] NRC, 1998.
[c] 4 to 4.5 lb/d of a corn or milo-soybean meal diet.

Ideally, sows needing more or less feed than the base amount would be identified at mating. The advantage of identifying the sows early in gestation is that small adjustments in the feeding rate (.5 to 1.0 pounds/day) are necessary to impact maternal weight gain. In addition, if a sow is not on target to reach a desired weight gain or

Table 3. Estimated adjustments in the amount of feed from a base amount to provide gestating sows in relation to number of days available to condition the sow.

No. days available to condition sow	Maternal weight gain change[a]		
	-20	20	40
	---------- lb feed/d from base amount[b] ----------		
115	-.5	.5	1.0
85	-.7	.7	1.4
55	-.7[c]	1.1	2.1
25	-.7[c]	2.3	4.6
Total feed adjustment, lb/sow	-57.5	57.5	115.0

[a]Relative to suggested maternal weight gains in Table 1.
[b]4 to 4.5 lb/d of a corn or milo-soybean meal diet.
[c]Although a greater reduction in sow feed intake would be necessary to reduce maternal weight gain by 20 lb during gestation, it is not recommended that feed intake be reduced further, because fetal development and future sow performance may be impaired.

body condition at farrowing, there is still time to impact her weight gain through further adjustments in her feeding rate.

However, preliminary research indicates increasing the amount of feed given to the sow between days 25 and 50 of gestation may benefit muscle development in the fetus which may improve performance during the growing/finishing period. If this is true, it may be best to condition a sow between days 25 and 50 of gestation.

Table 3 shows how much feed is required per day to alter maternal weight gain, depending on the number of days available to condition the sow. For example, if a sow is allowed 115 days to gain 20 pounds more maternal weight than normal, she should be fed 5 pounds/day more feed than the base amount. However, if she has only 55 days to gain 20 extra pounds of maternal weight, she requires 1.1 pounds of feed above base amount per day during that time.

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Growth and Carcass Responses of Barrows Fed a Corn-Soybean Meal Diet or Low-Protein Amino Acid-Supplemented Diets at Two Feeding Levels

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Summary and Implications

An experiment, with 39 barrows with high lean gain potential, was conducted to evaluate the growth responses of pigs fed a corn-soybean meal diet (CONTROL) and low-crude protein diets supplemented with crystalline lysine, threonine, tryptophan and methionine either on an ideal protein basis (IDEAL) or to a pattern similar to the control diet (AACON). In both cases the amino acid patterns were on a true ileal digestible basis. The initial and final body weights were 72.0 and 125.8 pounds. The diets were offered on an ad libitum basis or by feeding 80 percent of the ad libitum intake. Pigs were fed for 27 days. Three pigs were killed at the start of the experiment and three from each treatment were killed at the end to determine body chemical composition. Pigs fed the CONTROL diet grew faster and were more efficient than pigs fed the IDEAL and AACON diets. When feed intake was limited to 80 percent of ad libitum, weight gain decreased but efficiency tended to improve. The apparent fecal digestibility of protein was greatest in pigs fed the CONTROL diet and tended to be greater in pigs fed at 80 percent of ad libitum than those given ad libitum access to feed. Plasma urea concentrations were highest in pigs fed the CONTROL diet, regardless of feeding level. On a whole body basis, the protein concentration (g/kg) and the accretion rates of protein (g/d) were greater for pigs fed the CONTROL than for pigs fed the IDEAL and

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AACON diets. In summary, pigs fed the IDEAL and the AACON diets had lower growth performance, had less body protein and lower protein accretion rates than pigs fed the CONTROL diet. It remains unclear how to formulate low-crude protein amino acid-supplemented diets to ensure comparable growth performance and carcass characteristics to pigs fed corn-soybean meal diets.

Introduction

Recommendations for amino acid requirements of growing-finishing pigs in the new edition of the *Nutrient Requirements of Swine* are based on ideal dietary proportions among amino acids needed to support the daily potential for protein accretion in the whole body. Under experimental conditions, diets have been formulated using the ideal protein concept by reducing crude protein (CP) concentration and supplementing the limiting amino acids in crystalline form in ideal ratios, relative to lysine. Using this approach, diets have been formulated to be closer to the ideal protein than standard, high-CP diets.

Using diets formulated on the ideal protein concept, results in regard to growth performance and carcass characteristics and yield have been variable. These conflicting results deserve further clarification if amino acid recommendations are to be based on diets supplemented with crystalline amino acids in ideal ratios. The objective of this study was to evaluate different responses of pigs fed a control corn-soybean meal diet or low-CP diets supplemented with crystalline amino acids. The effect of two feeding levels was also evaluated.

Procedures

For the experiment, 39 crossbred barrows with high lean-gain potential (Danbred, USA, Inc.; Dorchester, Nebr.) with an initial and final body weight of 72.0 and 125.8 pounds were allotted to a randomized complete block experiment with a factorial arrangement of

Table 1. Die composition[a].

Item, percent	CONTROL[b]	IDEAL[b]	AACON[b]
Corn	74.34	84.51	84.37
Soybean meal, 46.5% CP	20.96	10.13	10.14
Tallow	2.00	2.00	2.00
Dicalcium phosphate	1.20	1.40	1.40
Limestone	.40	.40	.40
Salt	.30	.30	.30
Vitamin mix[c]	.70	.70	.70
Trace mineral mix[d]	.10	.10	.10
L-lysine•HC1	——	.33	.33
L-threonine	——	.08	.13
DL-methionine	——	.04	.08
L-tryptophan	——	.01	.05
Chemical composition			
CP, %[e]	15.90	11.70	12.29
Calcium, %[f]	.67	.68	.68
Phosphorus, %[f]	.56	.55	.55
GE, Mcal/lb[e]	1.79	1.77	1.77

[a]As-fed basis.
[b]CONTROL: corn-soybean meal diet; IDEAL: corn-soybean meal-amino acid-supplemented diet in ideal ratios; AACON: corn-soybean meal-amino acid-supplemented diet similar to the control diet.
[c]Supplied per kilogram of diet: retinyl acetate, 4400 IU; cholecalciferol, 550 IU; α-tocopherol acetate, 22 IU; menadione sodium bisulfite, 3.3 mg; riboflavin, 5.5 mg; d-pantothenic acid, 22 µg; niacin, 33 mg; choline chloride, 110 mg; vitamin B_{12} 22 mg; ethoxyquin, 1 mg.
[d]Supplied (mg/kg of diet): Cu (as $CuSO_4 \cdot 5H_2O$), 11; I (as $Ca[IO_3]_2 \cdot H_2O$), .22; Fe (as $FeSO_4 \cdot H_2O$), 110; Mn (as MnO), 22; Se (as Na_2SeO_3), .3; Zn (as ZnO), 110.
[e]Analyzed composition.
[f]Calculated.

Table 2. Analyzed total and calculated true ileal digestible amino acid composition (percent) of diets.

	CONTROL[a]		IDEAL[a]		AACON[a]	
Item	Total	True[b]	Total	True	Total	True
Arg	.99	.93	.66	.61	.67	.61
His	.43	.39	.33	.29	.33	.29
Ile	.63	.58	.47	.40	.49	.40
Leu	1.48	1.36	1.26	1.10	1.29	1.10
Lys	.83	.69	.77	.69	.74	.69
Met + Cys	.66	.48	.58	.45	.68	.48
Phe + Tyr	1.32	1.20	.98	.87	1.00	.87
Thr	.60	.52	.49	.48	.54	.52
Trp	.15	.17	.11	.13	.13	.17
Val	.72	.67	.54	.49	.57	.49
Ratios of calculated true ileal digestible amino acids relative to Lysine[c].						
Arg	135		88		88	
His	57		42		42	
Ile	84		58		58	
Leu	197		159		159	
Met + Cys	70		65		70	
Pbe + Tyr	174		126		126	
Thr	75		70		75	
Trp	25		19		25	
Val	97		71		71	

[a]CONTROL: corn-soybean meal diet; IDEAL: corn-soybean meal-amino acid-supplemented diet in ideal ratios; AACON: corn-soybean meal-amino acid-supplemented diet similar to the control diet.
[b]Calculated true ileal digestible amino acids estimated from true ileal digestible values from corn and soybean meal (NRC, 1998).
[c]On a calculated true ileal digestible basis.

Table 3. Performance of barrows fed a control or low-CF amino acid-supplemented diets at two different feeding levels[a].

	Diets	CONTROL		IDEAL		AACON		
Item	Levels	100	80	100	80	100	80	SEM[b]
Initial wt., lb		71.88	71.93	71.88	71.99	72.21	72.21	.987
Final wt, lb[cd]		132.55	124.40	128.55	118.81	130.15	119.95	1.842
ADG, lb[cd]		2.25	1.94	2.09	1.74	2.14	1.76	.053
ADFI, lb[d]		4.74	3.86	4.85	4.01	4.89	4.01	.121
ADG/ADFI[ce]		.47	.50	.43	.43	.44	.44	.008
Apparent nutrient digestibilities								
Dry matter		89.31	89.84	89.70	89.72	89.90	90.83	0.487
Crude protein[ce]		86.54	87.28	82.37	83.48	84.45	85.90	0.678
Energy		88.20	88.89	88.21	88.34	88.58	88.66	0.524

[a]DIETS=CONTROL: corn-soybean meal diet; IDEAL: corn-soybean meal-amino acid-supplemented diet in ideal ratios; AACON: corn-soybean meal-amino acid-supplemented diet similar to the control diet. FEEDING LEVELS 100: pigs had ad libitum access to feed; and 80: pigs were offered 80 percent of feed consumed for pigs with ad libitum access to feed.
[b]SEM = Standard error of the mean.
[c]Diet effect, P < .05.
[d]Level effect, P < .05.
[e]Level effect, P< .10.

six treatments. Three diets were combined with two levels of feed intake. The diets used in the experiment are presented in Table 1. Diets were offered for 27 days. In the IDEAL and AACON diets, the protein concentration was reduced approximately four percentage units from the CONTROL diet. The first four limiting amino acids (lysine, threonine, tryptophan and methionine) were added as crystalline amino acids to meet the lysine concentration of the CONTROL diet and to provide an amino acid pattern (relative to lysine) similar to the ideal pattern developed at the University of Illinois (IDEAL) or to provide an amino acid pattern (relative to lysine) similar to the pattern of the CONTROL diet (AACON). The concentration of lysine and the ratios used for the next three limiting amino acids were based on calculated true ileal digestible values (Table 2). Results of analyzed total amino acid composition of the diets (Table 2) show lysine concentration in the IDEAL and AACON diets was lower than in the CONTROL diet. However, based on calculated values, all three diets contained the same amount of lysine on a true ileal digestible basis.

Two subgroups of six pigs were formed within each dietary treatment and allotted to one of two feeding levels: pigs with ad libitum access to their diet and pigs offered 80 percent of the feed consumed by the pigs that had ad libitum access to the diet on a daily basis.

Feeders from pigs in the ad libitum group were weighed daily to calculate the feed to be offered to pigs allotted to the 80 percent feeding level for the next 24 hours. Restricted-fed pigs were pair fed within each block and diet. Pigs had ad libitum access to water and were fed three times a day throughout the experiment at 9 a.m., 1 p.m. and 5 p.m. Pigs were penned individually in an environmentally controlled room with temperature maintained at 68°F and constant lighting. Pens were fully slated, with a space allocation of 16 ft^2, a one-hole self-feeder and a nipple waterer. Pig weights and feed intakes were recorded weekly to determine average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (ADG/ADFI).

Blood samples from each pig were taken at the start of the trial and every week thereafter. Plasma was separated and analyzed for urea, glucose and nonesterified fatty acids (NEFA). The response of each of these metabolites versus week of the study was examined. During the third week of the study, .25 percent of chromic oxide (Cr_2O_3) was added to the diet as an indigestible marker. Fecal samples from each barrow were collected for three consecutive days to calculate the apparent digestibility of dry matter, crude protein and energy.

Three pigs were killed at the start of the experiment and three from each treatment were killed at the end to determine body chemical composition. The whole body was divided in two fractions: the noncarcass, which included the blood, skin, head, feet, leaf fat, mesentery and all organs, including the empty stomach and intestines, and the carcass, which included the meat and bones. Initial weight and body chemical composition of the initial slaughtered pigs were used to estimate the initial body chemical composition of pigs slaughtered at the end of the experiment. Accretion rates of dry matter CP, fat and ash in the noncarcass, carcass and whole body (noncarcass and carcass together) were estimated as the difference between the total weight of chemical components at the end and at the beginning of the experiment divided by the number of days on treatments.

Results and Discussion

Results of growth performance of barrows and apparent nutrient digestibilities of diets are presented in Table 3. Pigs fed the CONTROL diet had greater (P < .05) final body weight, ADG and ADG/ADFI than pigs fed the IDEAL and AACON diets. Growth performance of pigs fed the IDEAL and the AACON diet was similar. When feed intake was limited to 80 percent of ad libitum, ADG decreased (P < .01) but ADG/ADFI tended to improve (P < .10). These findings agree with previous results published in the 1996

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and 1998 Nebraska Swine Reports indicating barrows fed a corn-soybean meal diet had better performance than those fed an ideal protein diet similar to the one used in this report.

The apparent digestibility of protein was greatest in pigs fed the CONTROL diet (P < .01), and was greater (P < .01) in pigs fed the AACON diet than in pigs fed the IDEAL diet. These results were expected because there is an inverse relationship between protein level and digestibility. Greater crystalline amino acid additions may have caused the greater apparent digestibility in the AACON diet compared with the IDEAL diet. There was a trend (P < .10) for greater apparent protein digestibility in pigs fed at 80 percent of ad libitum. This result was also expected. Generally, there is an inverse relationship between feeding level and digestibility.

Plasma concentrations of urea, glucose and NEFA are presented in Figures 1, 2 and 3, respectively. Plasma urea concentrations were lower in pigs fed the IDEAL and AACON diets than in pigs fed the CONTROL diet, regardless of feeding level (P < .01). For pigs fed the CONTROL diet, the urea concentrations were lower when feed intake was 80 percent of ad libitum (diet level, P < .01). Reductions in plasma urea concentrations have been reported previously in pigs fed low CP diets supplemented with crystalline amino acids as the IDEAL and AACON diets used in this research. Plasma glucose concentrations did not differ among treatments. Plasma NEFA concentrations varied but were greatest (P < .01) in pigs fed the AACON diet and in pigs that had ad libitum access to feed.

Results of body and body fraction weights and body fraction chemical composition are presented in Table 4. Final body weight and body fraction weights were similar among diets. Pigs allowed ad libitum access to feed had greater (P < 05) final body, noncarcass,

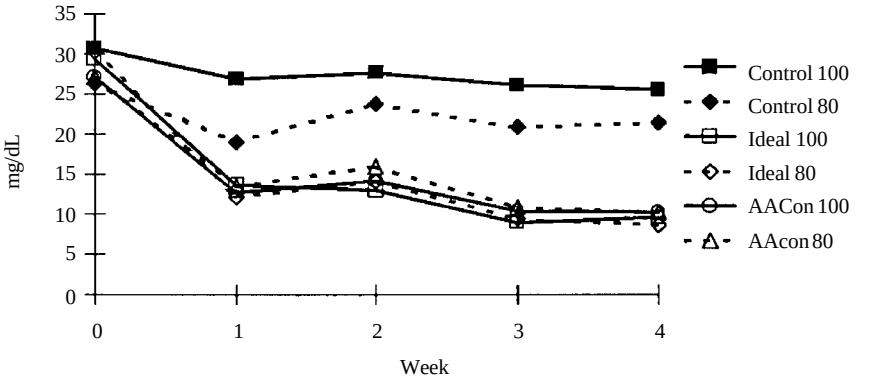

Figure 1. Plasma urea concentrations of barrows fed a corn-soybean meal diet (Control) or low-protein amino acid-supplemented diets either on an ideal ratio basis (Ideal) or to a ratio similar to the Control diet (AACon) at two feeding levels (Diet x Level, P<.01, SEM=.459; Diet x Time, P<.01, SEM=.592).

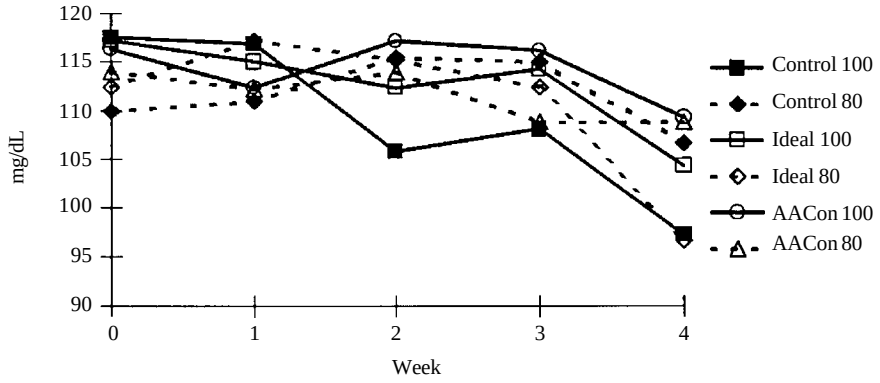

Figure 2. Plasma glucose concentrations of barrows fed a corn-soybean meal diet (Control) or low-protein amino acid-supplemented diets either on an ideal ratio basis (Ideal) or to a ratio similar to the Control diet (AACon) at two feeding levels (Time, P<.01, SEM = 1.404).

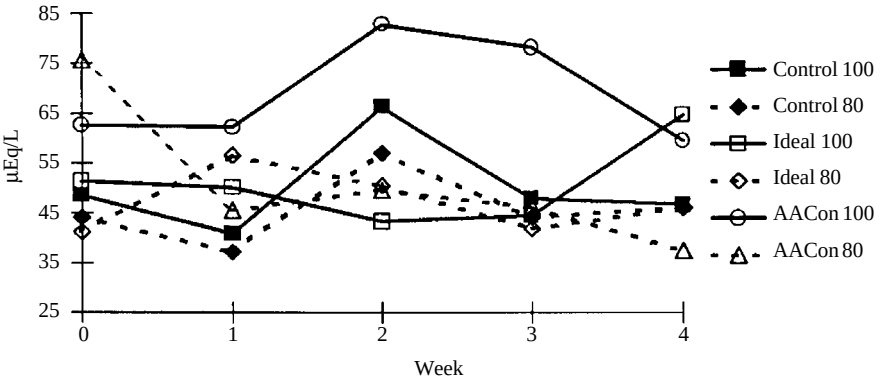

Figure 3. Plasma NEFA concentrations of barrows fed a corn-soybean meal diet (Control) or low-protein amino acid-supplemented diets either on an ideal ratio basis (Ideal) or to a ratio similar to the Control diet (AACon) at two feeding levels (Diet, P<.05, SEM=3.238; Level, P<.05, SEM=2.644).

Table 4. Body and body fraction weights and chemical composition of barrows fed a control or low-CP amino acid-supplemented diets at two different feeding levels[a].

Item[b]	Diet	CONTROL		IDEAL		AACON		SEM[c]
	Level	100	80	100	80	100	80	
Final body wt, lb[d]		125.35	115.68	122.69	113.67	123.02	114.03	2.09
Body fractions, lb								
Noncarcass[d]		38.22	35.93	38.66	34.98	38.62	35.58	.88
Carcass[d]		80.85	72.02	76.84	71.51	77.35	71.00	2.16
Whole body[d]		119.07	107.95	115.50	105.85	115.97	106.60	2.47
Body fractions chemical composition, g/kg								
Noncarcass								
Water[e]		600	629	581	576	600	600	11.70
Protein		154	147	148	152	150	144	3.26
Fat		220	191	231	230	216	219	14.15
Ash		24	22	22	24	22	22	1.97
Carcass								
Water		624	619	627	619	624	629	16.04
Protein[e]		184	183	172	179	174	179	3.14
Fat		168	181	170	181	185	166	20.00
Ash		29	30	30	28	29	27	1.42
Wholebody								
Water		616	623	611	605	617	620	11.69
Protein[e]		174	171	164	170	166	167	2.71
Fat		185	184	191	197	194	184	15.11
Ash		27	28	27	26	27	26	1.07

[a]DIETS=CONTROL: corn-soybean meal diet; IDEAL: corn-soybean meal-amino acid-supplemented diet in ideal ratios; AACON: corn-soybean meal-amino acid-supplemented diet similar to the control diet. FEEDING LEVELS=100: pigs had ad libitum access to feed; and 80: pigs were offered 80 percent of feed consumed for pigs with ad libitum access to feed.
[b]Noncarcass: included the head, skin, feet, blood, all organs, and internal fat; carcass: included the meat and bones; whole body: sum of noncarcass and carcass.
[c]SEM=Standard error of the mean.
[d]Level effect, P < .05.
[e]Diet effect, P < .05.

Table 5. Tissue accretion rates on body fractions of barrows fed a control or low-CP amino acid-supplemented diets at two different feeding levels[a].

Item[b]	Diet	CONTROL		IDEAL		AACON		SEM[c]
	Level	100	80	100	80	100	80	
Noncarcass, g/d								
Water[de]		142	137	134	89	149	116	9.40
Protein[e]		43	32	40	31	41	29	2.31
Fat		87	61	95	78	83	76	10.92
Ash		7	5	6	5	6	5	1.27
Carcass, g/d								
Water[e]		405	302	365	298	365	305	22.87
Protein[ef]		119	91	92	86	96	83	7.30
Fat		136	131	129	129	151	109	29.03
Ash[g]		20	18	19	14	18	14	1.16
Wholebody, g/d								
Water[e]		546	440	499	387	514	421	29.39
Protein[ef]		162	123	132	117	137	113	8.58
Fat		223	192	224	207	235	184	31.54
Ash[e]		27	22	25	19	24	18	1.39

[a]DIETS=CONTROL: corn-soybean meal diet; IDEAL: corn-soybean meal-amino acid-supplemented diet in ideal ratios; AACON: corn-soybean meal-amino acid-supplemented diet similar to the control diet. FEEDING LEVELS=100: pigs had ad libitum access to feed; and 80: pigs were offered 80 percent of feed consumed for pigs with ad libitum access to feed.
[b]Noncarcass: included the head, skin, feet, blood, all organs, and internal fat; carcass: included the meat and bones; whole body: sum of noncarcass and carcass.
[c]SEM=Standard error of the mean.
[d]Diet effect, P < .10.
[e]Level effect, P < .05.
[f]Diet effect, P < .05.
[g]Level effect, P < .10.

carcass and whole body weights. Water concentration in the noncarcass was greater (P < .05) in pigs fed the CONTROL than in pigs fed the IDEAL and AACON diets and tended to be greater (P < .10) in pigs fed the AACON than in pigs fed the IDEAL diet. Protein concentration in the carcass and whole body was greatest (P < .05) in pigs fed the CONTROL diet.

Results of tissue accretion rates on body fractions are presented in Table 5. Water accretion rate in the noncarcass tended to be greatest in pigs fed the CONTROL diet and tended to be lowest in pigs fed the IDEAL diet (P < .10). Protein accretion rate in the carcass and whole body was greatest (P < .05) in pigs fed the CONTROL diet. These results, together with the reduction in protein concentration, are in agreement with other reports in which a reduction in lean percentage or muscle yield was observed in pigs fed low-CP amino acid supplemented diets. Pigs that had ad libitum access to the diet had greater (P < .05) water and protein accretion rates in the noncarcass, carcass and whole body. Fat accretion rate in the noncarcass tended to be greater (P < .10), ash accretion rate in the carcass tended to be greater (P < .10) and in the whole body was greater (P < .05) in pigs allowed ad libitum access to feed than in pigs fed at 80 percent of ad libitum.

Conclusion

Reductions in growth performance, plasma urea concentrations, body protein concentration and body protein accretion rate were observed in pigs fed the IDEAL and the AACON diets compared to pigs fed the CONTROL diet. This suggests the formulated amino acid patterns in the IDEAL and AACON diets were not "ideal" for the pigs used in this research.

[1]Sergio Gomez is a graduate student, Phillip Miller is an associate professor, Austin Lewis is a professor and Hsin-Yi Chen is a research technologist in the Department of Animal Science.

Pork 101
A Short Course Focusing on the Importance of Pork Quality and Consistency

Dennis E. Burson
Dana J. Hanson[1]

As we move towards the next century, pork producers face many challenges. The Pork Quality Audit in 1994 identified consistency of the meat product, meat quality and food safety as major issues producers can't afford to ignore.

To introduce participants to these important segments of the pork industry, a three-day, hands-on short course has been developed at the University of Nebraska, with the assistance of the American Meat Science Association, the National Pork Producers Council, Michigan State University and Texas A&M University.

Course Objectives

The course provides:

a. In-depth training on quality and consistency issues in the pork industry.
b. Insight on value differences in swine, pork carcasses, pork primals and processes pork products due to quality variation.
c. A framework allowing participants in all phases of pork production to implement management and production changes to increase value through improvements in quality and consistency.

The target audience for the three-day course is individuals involved in the production, processing and marketing of pork and might include pork producers, veterinarians, researchers, educators, pork packers, meat processors, retail merchandisers, food service distributors, exporters, allied industry and media. To ensure everyone can participate in the hands-on learning activities, each session is limited to 32 participants.

Course Activities

The activities for the course center around two groups of market hogs. One group of four market hogs is used during the course for live evaluation and slaughter demonstrations. A second group of eight market hogs is slaughtered before the workshop to provide carcasses for fabrication, taste panel evaluations and quality measurements. The use of both sets of market hogs allows for the course to cover quality and consistency issues from production to consumption.

On the first day, participants have the chance to evaluate four live hogs, including a lean or fat animal and a light weight or heavy weight animal. These hogs are slaughtered on the second day of the workshop, and demonstrations, such as measuring carcass pH and carcass composition, HACCP (hazard analysis critical control point) systems for slaughter, hot processing of pork, microbiological interventions during slaughter and microbiological sampling for generic *E. coli*, are included. On the third day of the course the carcasses from the slaughtered hogs are evaluated for lean quality and quantity traits and are priced according to industry buying programs.

A second set of market hogs of diverse genetic background are recorded on video and slaughtered prior to the course. These carcasses are used during the workshop to give participants the chance for hands-on lessons in carcass evaluation, carcass fabrication, curing of the hams and bellies and taste panel evaluations.

Other activities provide unique learning experiences for the participants. For example, the first day's dinner provides participants with two chops to rate for tenderness and taste. The chops can come from loins preselected for opposite quality traits such as high marbling versus low marbling and pale, soft and exudative (PSE) versus dark, firm and dry (DFD). Different quality contrasts are served to different individuals to cover a number of quality comparisons during the meal. The information is summarized and presented to the participants at the end of the first day.

Course Outline

The following agenda is followed for each Pork 101 short course.

DAY 1

4 p.m.	Welcome
	Impact of genetics on lean quality
	Grading and evaluation of live animals
	Pork carcass lean value pricing
	Evaluate market swine
5:30 p.m.	Quiz on pork quality
	Dinner and taste test
	Perspective on quality and consistency
	Group selects one of eight hogs for fabrication
	Review results of dinner taste test

DAY 2

7 a.m.	Breakfast
7:30 a.m.	Pork carcass evaluation and review of eight carcasses for fabrication
8 a.m.	Pork slaughter demonstration HACCP and microbial interventions pH and other quality measurements Measures of carcass composition Hot boning demonstration
10:30 a.m.	Pork carcass fabrication
12 p.m.	Lunch
1 p.m.	Value-added product demonstration including bacon, low-fat ham and fresh pork sausage Demonstration of PSE and DFD pork processing Marinated pork products

DAY 3

7 a.m.	Breakfast
7:30 a.m.	Pork Quality Assurance Review of quality and consistency on carcasses Taste panel evaluation of hog used in the demonstrations Assessment of carcass value Evaluation of cured products made the previous day Carcass grading demonstration
12 p.m.	Lunch Adjourn

Course Evaluation

Past evaluations by participants indicate the course is successful and many participants had very positive remarks about it. When asked to identify things they liked about the course, the most popular answers related to "the hands-on nature of the course" and the "evaluation of the market hog from live to the meat products."

Development of Intervention Strategies to Extend the Shelf-Life of Fresh Ground Pork

David M. Gaebler
Roger W. Mandigo[1]

Summary and Implications

The effects of storage time, packaging atmosphere and raw material source on shelf-life of fresh ground pork were studied. Fresh ground pork (18 percent fat) was packaged in an atmosphere of 80:20 percent 0_2:CO_2 or 100 percent CO_2 and placed in unlighted refrigerated storage (34°F) for a period of two or eight days to simulate distribution time of the product from manufacturer to retail merchandiser. Products were then placed under lighted storage for eight additional days (100 foot candles, 34°F) to simulate retail display conditions. Ground sirloin had higher percent surface metmyoglobin (darkness and brown color) than ground pork shoulder after eight days of lighted storage. Lipid oxidation (rancidity) was higher in ground pork shoulder than ground pork sirloin. Pork shoulder had higher a (redness) values than pork sirloin in both atmospheres. Microbial loads (aerobic microorganisms) were higher in product stored eight days versus two days; however, total aerobic microbial loads did not exceed 10^6 (the level commonly used to indicate microbial spoilage) for product stored in either atmosphere. Carbon dioxide successfully extends product shelf-life up to eight days under lighted storage conditions.*

Introduction

The preparation of meat products for retail display has changed dramatically over the last 20 years. Large supermarket chains have reduced or eliminated in-store preparation of fresh red meat products to reduce labor and capital equipment costs. Today, meat products are prepared, packaged and labeled at large processing facilities, and shipped in refrigerated trucks to centralized distribution warehouses which then distribute products to individual stores. A consequence of this change is the necessity of longer shelf-life for products to reach the consumer. Fresh red meats packaged in oxygen permeable film have an expected shelf-life of two to three days under retail display conditions. One method for increasing shelf-life of refrigerated meats is to modify the atmosphere within the package. The shelf-life of fresh meat can be increased to six to 10 days with modified atmosphere packaging in a high-oxygen environment, and up to 21 days in a low-oxygen environment.

Modified Atmosphere Packaging (MAP) is one of several methods used by processors to control microbial spoilage of food products. Normal atmosphere contains 20.9 percent oxygen and 0.1 percent carbon dioxide. By increasing the carbon dioxide levels in the package, growth of aerobic spoilage organisms can be delayed, thereby extending the shelf-life of the meat product.

The two most frequently used atmospheres in MAP products are an 80:20 percent mixture of oxygen and carbon dioxide and 100 percent carbon dioxide. These atmospheres use different strategies to achieve the same result. The 80:20 percent O_2:CO_2 mixture uses higher-than-normal carbon dioxide levels to reduce aerobic microorganisms in combination with higher-than-normal oxygen levels to help maintain red meat color normally associated with freshness. The atmosphere is sealed into individual packages which

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[1]Dennis E. Burson is an associate professor and Dana J. Hanson is a graduate student in the Department of Animal Science.

are boxed and shipped to the retail store, ready for display.

The 100 percent CO_2 product is prepared in a traditional oxygen permeable packaging, placed into a master container which is filled with carbon dioxide and then sealed. Packages are removed from the master pack, allowed to bloom to a bright red color and placed on the shelf for sale.

The objectives of this research were to determine differences in characteristics of ground pork placed in lighted storage due to: effects of atmosphere (80:20 percent O_2:CO_2 or 100 percent CO_2), length of storage (two days versus eight days unlighted storage) and raw material source (pork sirloin with pork loin fat trim or pork shoulder meat).

Materials and Methods

Fresh pork sirloin, pork loin fat trim and pork shoulder meat were purchased from a commercial processor five days after slaughter. The meat was analyzed for fat content and fresh sirloin meat and pork loin fat trim were formulated to a fat content equal to the shoulder meat (18 percent fat). The pork was ground through a 1/8 inch plate, chilled and made into half-pound portions. Ground pork was placed into packages and filled with either 100 percent carbon dioxide or an 80:20 percent mixture of oxygen and carbon dioxide. Packages of ground pork were placed in unlighted storage (34°F) for either two or eight days to simulate the range of time prepackaged meat would spend in route to retail outlets. Packaged products were then placed under light (1076 lux light, 34°F) for eight days to simulate lighting conditions found in retail display cases. The products were kept in their original atmospheric environment throughout the study. Individual packages were opened immediately prior to chemical and physical analysis. Product was evaluated every two days (zero to eight days of lighted storage) for total bacteria (APC), coliforms, psychrotropic bacteria, exterior color L* (lightness), a* (redness) and b* (yellowness) values, surface metmyoglobin and surface

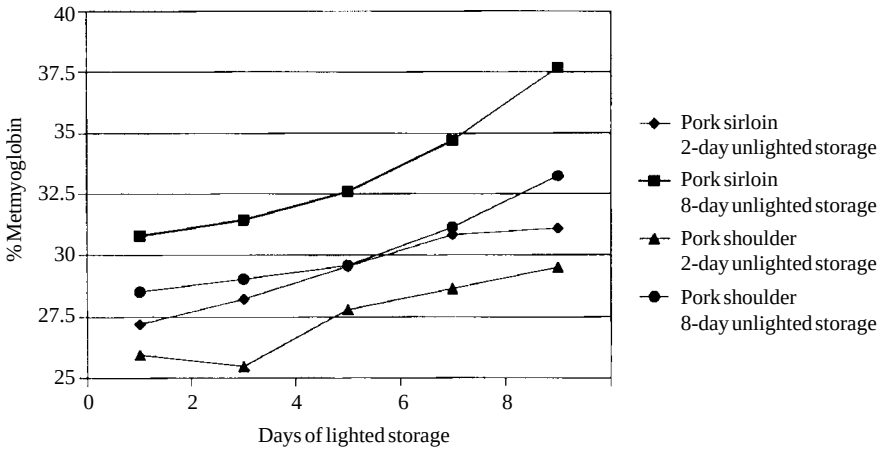

Figure 1. Surface metmyoglobin of ground pork in 80:20 percent oxygen:carbon dioxide modified atmosphere packaging.

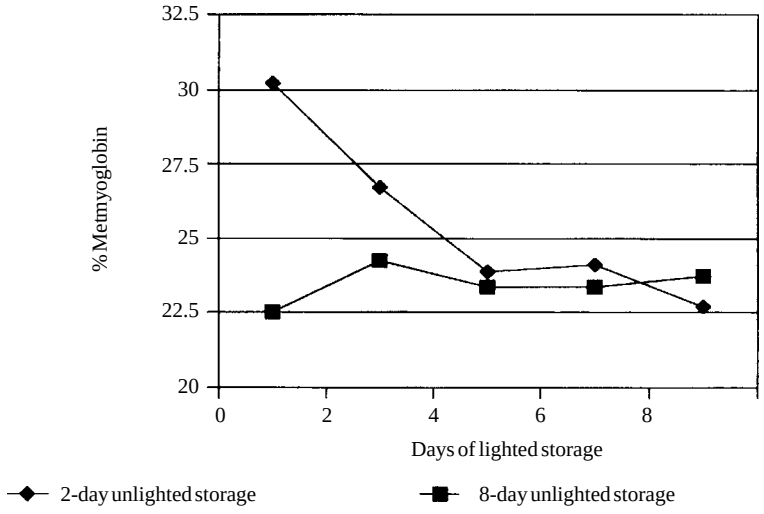

Figure 2. Surface metmyoglobin of ground pork in 100 percent carbon dioxide for product held either two or eight days in unlighted storage prior to lighted retail display.

metmyoglobin reducing ability (MRA), pH and oxidation reduction potential. Lipid oxidation was also measured and reported as thiobarbituric acid reactive substances (TBARS). Surface metmyoglobin formation was measured by obtaining reflectance readings through eight days of lighted storage.

Results and Discussion

In a high-oxygen environment (80:20 percent oxygen:carbon dioxide) surface metmyoglobin was higher for ground pork from sirloin than for ground pork shoulder meat (Figure 1) in product held two or eight days (unlighted storage) prior to lighted retail display. Surface metmyoglobin levels remained below 50 percent throughout eight days of lighted retail storage (50 percent metmyoglobin is the value commonly used as the level above which consumers reject meat for purchase based on color perception). Surface metmyoglobin increased during lighted storage from 27.5 percent to 31 percent (sirloin) and 31 percent to 37.5 percent (shoulder) after two days of unlighted storage and from 31 percent to 37.5 percent (sirloin) and 28 percent to 33 percent (shoulder) after eight days of unlighted storage. Surface metmyoglobin of products in an atmosphere of 100 percent CO_2 decreased over time from 30 percent to 23 percent (after two days of unlighted storage) due to enzymatic reduction of the meat system, but remained relatively constant at 23 percent after eight

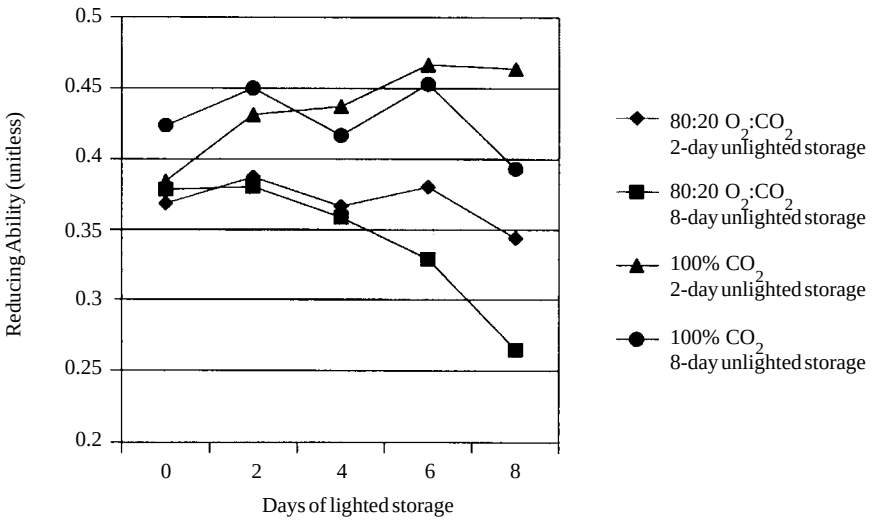

Figure 3. Metmyoglobin reducing ability of ground pork in modified atmosphere packaging.

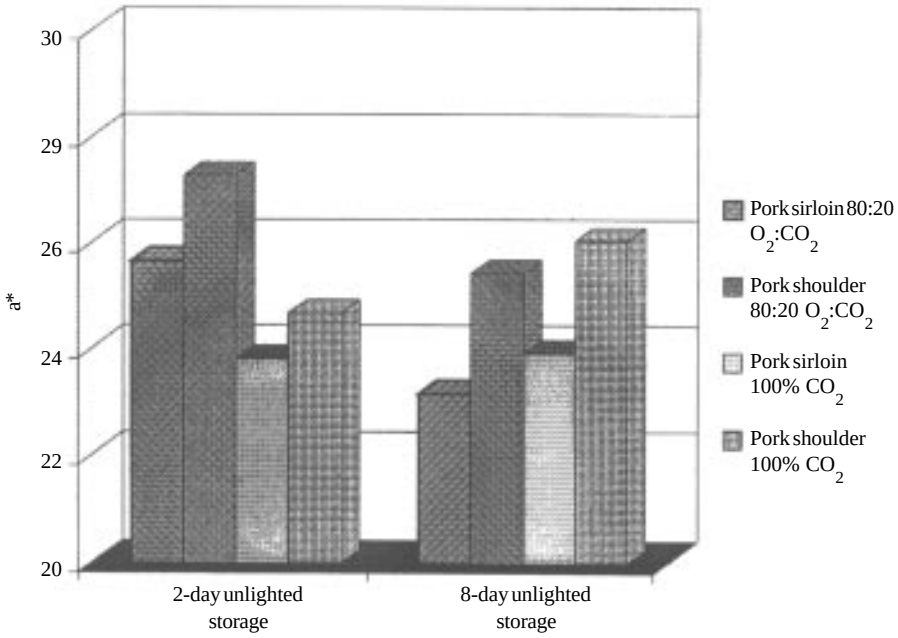

Figure 4. Changes in surface redness due to different meat source and atmosphere.

Table 1. Fatty acid profile of ground pork.

	Ground Pork Sirloin		Ground Pork Shoulder	
Fatty Acid	Mean (n=8)	SEM[a]	Mean (n=8)	SEM[a]
Mystiric Acid (14:0)	1.40	0.14	1.40	0.06
Palmitic Acid (16:0)	23.23	0.56	22.93	0.72
Palmitoleic (16:1)	3.30	0.22	3.94	0.19
Stearic (18:0)	12.65	0.52	11.67	0.30
Oleic (18:1)	43.48	0.84	45.16	0.55
Linoleic (18:2)	15.48	0.44	14.45	0.76
Arachidonic (18:3)	0.46	0.09	0.55	0.13
Total	100.00		100.00	

[a]Standard error of the mean.

days of unlighted storage (Figure 2). Metmyoglobin reducing ability of ground pork packaged in 100 percent carbon dioxide was higher than ground pork packaged in 80:20 percent oxygen:carbon dioxide (Figure 3). In an anaerobic environment, enzymes will reduce metmyoglobin to deoxymyoglobin, reducing the level of surface metmyoglobin (Figure 2) over time, as long as reducing equivalents are not depleted.

Lipid oxidation of ground pork is measured as thiobarbituric acid reactive substances (TBARS). A TBARS value of 1.0 is considered the threshold value for consumers to detect rancidity in fresh ground pork. Ground shoulder meat was higher in unsaturated fatty acids (palmitoleic, oleic and arachidonic fatty acids) than ground sirloin (Table 1). Unsaturated fatty acids contribute to higher lipid oxidation and correspondingly higher TBARS values. The TBARS values for ground pork in 100 percent carbon dioxide remained below 0.3 mg malonaldehyde/kg meat throughout lighted storage and there were no significant differences between meat sources (data not shown). Surface a* values (redness) were higher for pork shoulder than for pork sirloin (Figure 4) for both atmospheres.

Total aerobic plate counts, coliforms and psychotropic bacteria counts are given in Tables 2 through 4. In an 80:20 percent O_2:CO_2 atmosphere, products held for eight days in unlighted storage had higher bacterial levels than products held for two days, although levels remained below 10^6 throughout eight days of lighted storage. Aerobic plate counts were lower for products stored in 100 percent CO_2 and remained low throughout lighted storage (Table 2). Carbon dioxide has an inhibitory effect on the growth of microorganisms by both extending the lag phase of bacteria prior to the growth phase and decreasing pH due to increased solubility of carbon dioxide in meat at low temperatures. Psychotropic plate counts and coliforms remained low throughout lighted storage in both atmospheres (Tables 3 and 4).

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Table 2. Mean aerobic plate counts for ground pork in modified atmosphere packaging.

Treatment			Aerobic plate counts (log_{10} cf.u./gram					
			Day 0	Day 2	Day 4	Day 6	Day 8	SEM
80:20 O_2:CO_2		2-day unlighted storage	3.27^{a}	3.25^{a}	3.41^{ab}	3.81^{bc}	3.94^{c}	0.12
		8-day unlighted storage	3.95^{c}	4.14^{d}	4.65^{e}	5.22^{f}	5.51^{g}	0.12
		Pork sirloin	3.38^{a}	3.59^{b}	3.96^{c}	4.36^{d}	4.63^{e}	0.09
		Pork shoulder	3.85^{c}	3.80^{cd}	4.11^{cd}	4.67^{e}	4.82^{e}	0.09
100% CO_2	Pork sirloin	2-day unlighted storage	3.19^{w}	3.05^{w}	3.14^{w}	3.17^{w}	3.13^{w}	0.06
		8-day unlighted storage	3.15^{w}	3.21^{w}	3.26^{w}	3.63^{y}	4.00^{z}	0.06
	Pork shoulder	2-day unlighted storage	3.37^{x}	3.34^{wx}	3.41^{x}	3.51^{x}	3.47^{x}	0.06
		8-day unlighted storage	3.49^{xy}	3.33^{wx}	3.58^{y}	3.49^{y}	3.56^{y}	0.06

$^{a-g,w-z}$Means within an atmosphere treatment with the same subscript are not significantly different (P<0.05).

Table 3. Mean psychotropic plate counts for ground pork stored in modified atmosphere packaging.

Treatment			Psychrotrophic plate counts (log_{10} cf.u./gram)					
			Day 0	Day 2	Day 4	Day 6	Day 8	SEM
80:20 O_2:CO_2		2-day unlighted storage	2.79^{a}	3.33^{b}	3.42^{b}	13.68^{c}	4.31^{de}	0.08
		8-day unlighted storage	4.09^{d}	4.39^{e}	5.11^{f}	5.61^{g}	5.87^{b}	0.08
100% CO_2	Sirloin	2-day unlighted storage	2.39^{w}	2.62^{wx}	2.52^{w}	2.42^{w}	2.68^{wx}	0.14
		8-day unlighted storage	2.06^{wx}	2.52^{w}	3.23^{y}	3.49^{y}	4.11^{z}	0.14
	Shoulder	2-day unlighted storage	2.78^{wx}	3.32^{y}	3.10^{y}	2.59^{wx}	2.85^{xy}	0.14
		8-day unlighted storage	2.91^{xy}	2.52^{w}	3.27^{y}	3.33^{y}	3.61^{y}	0.14

$^{a-d,w-z}$Means within an atmosphere treatment with the same letter are not significantly different (P<0.05).

Table 4. Mean coliform plate counts for ground pork stored in modified atmosphere packaging.

Treatment		Coliforms (c.f.u./gram)					
		Day 0	Day 2	Day 4	Day 6	Day 8	SEM
80:20 O_2:CO_2	2-day unlighted storage	15^{a}	14^{a}	20^{a}	16^{a}	12^{a}	1.15
	8-day unlighted storage	12^{a}	51^{b}	19^{a}	20^{a}	18^{a}	1.15
	Pork Sirloin	13^{a}	52^{d}	38^{cd}	35^{c}	22^{b}	1.15
	Pork Shoulder	14^{a}	13^{a}	10^{a}	$<10^{a}$	$<10^{a}$	1.15
100% CO_2	2-day unlighted storage	14^{w}	11^{x}	$<10^{x}$	$<10^{x}$	$<10^{x}$	1.11
	8-day unlighted storage	$<10^{x}$	$<10^{x}$	$<10^{x}$	$<10^{x}$	$<10^{x}$	1.11

$^{a-b,w-x}$Means within an atmosphere treatment with the same letter are not significantly different (P<0.05).

Conclusions

The generally excepted shelf-life of red meat packaged in oxygen permeable films is two to three days. Modified atmosphere packaging was successful in extending shelf-life of ground pork from two to three days of lighted storage to at least six days for color and up to eight days for microbial spoilage. Ground pork shoulder meat had greater redness than ground pork sirloin meat. Microbial spoilage of ground pork was maintained below spoilage levels for up to eight days of lighted display. Ground pork packaged in an atmosphere of 80:20 percent O_2:CO_2 can be held in unlighted storage for up to eight days and achieve an additional six to eight days of lighted storage shelf-life, provided ground pork is produced from freshly slaughtered meats and processed in a clean, sanitary environment with good temperature control.

[1]David M. Gaebler is a graduate student and Roger W. Mandigo is a professor in the Department of Animal Science.

Development and Use of Pork Skin Fat Emulsion Gels in Low-Fat, High-Added-Water Bologna

Timothy D. Schnell
Roger W. Mandigo[1]

Summary and Implications

Reduced-lean pork trimmings (~70 percent fat and 30 percent lean) have low economic value due to inherent high fat content. Mechanically modified pork skin was used to extend reduced-lean pork trimmings by making a fat emulsion gel, lowering fat content by dilution in an attempt to increase the value of reduced lean trimmings. The first objective was to extend reduced-lean pork trimmings by creating a pork skin fat emulsion gel (FG) and to characterize and optimize the functionality of FG from combinations of pork skin, reduced-lean trimmings and added water (AW). The next objective was to incorporate the best FG into low-fat bologna. Fat emulsion gels were characterized and optimized using combinations of pork skin (3 to 10 percent), AW (25 to 50 percent) and reduced-lean pork trimmings (20 to 40 percent final fat content). To make FG, flaked pork skin and water were chopped and heated to 160°F to solubilize collagen. The cooled (<85°F) skin/water mixture, combined with reduced-lean trimmings and salt (4 percent), were then chopped to 105°F. Regression analysis predicted optimal emulsion stability (lowest ml fluid released/100g of FG during simulated cooking) in FG occurred with 5 to 6 percent pork skin. Incorporation of selected FG, with known characteristics, into low-fat comminuted pork products could improve water binding properties and help achieve desired sensory properties when used at appropriate levels. It was determined FG should be formulated with 6 percent skin for optimal functionality and at least 30 percent fat to utilize more reduced-lean trimmings. Pork skin fat emulsion gels with the best emulsion stability [30 percent fat, 25 percent added water (AW)], the best hydration/softest texture (30 percent fat, 50 percent AW) and the most economical FG (40 percent fat, 50 percent AW) were selected to evaluate how FG with known characteristics would impact low-fat/high-added-water bologna. There was a low-fat/high-added-water control (10 percent fat/30 percent AW) and a 30 percent fat/10 percent AW control. Common problems associated with low-fat/high-added-water bologna include dark color and soft texture. The texture of bologna containing FG was improved, it required more force to fracture and was harder (P<0.05) than control low-fat/high-added-water bologna but similar (P>0.05) to the full-fat control. The sensory panel found bologna containing FG was more like the full-fat control bologna and had a lighter (P<0.05) color and a more (P<0.05) springy and firm texture than the low-fat/high-added-water control. The value of reduced-lean trimmings could be increased by production and incorporation of fat emulsion gels into comminuted meat products.

Introduction

Reduced-lean pork trimmings, composed of about 70 percent fat and 30 percent lean, still contain valuable lean that functions to bind water and emulsify fat. It is difficult for processors to utilize reduced-lean trimmings because the lean is embedded in an excessive amount of fat. Also, because it is expensive to remove the lean by trimming with a knife to make a product that consumers will accept, reduced-lean trimmings have low economic value. Flaked pork skin has been shown to bind as much as 600 percent added water (AW) when heated to 160°F and cooled to form a gel. Incorporation of pork skin gels into comminuted meat products improves water binding properties and enhances sensory characteristics by reducing hardness and increasing juiciness of low-fat bologna. Pork skin could be used to extend reduced-lean pork trimmings by binding AW in a fat emulsion gel (FG). The resulting FG would have lower fat content by dilution and would be easier for processors to use in sausage-type meat products. The value of reduced-lean pork trimmings may be increased if FG has texture modifying attributes useable in ground and emulsified meat products. By characterizing FG, it may be possible to create a comminuted meat product with desired texture properties by utilizing a selected FG (with known texture characteristics) as a raw material ingredient.

The demand for low-fat comminuted meat products led processors to remove fat from sausages, resulting in a hard, dry product. To replenish moisture in low-fat sausages, up to 30 percent water has been added. Previous research indicates that as fat was replaced by water, bologna containing 30 percent added water and 10 percent fat was darker in color, softer,

(Continued on next page)

more juicy and had increased problems with purge compared to full-fat bologna. It was hypothesized that incorporation of selected FG into low-fat/high-added-water bologna could modify functional and textural attributes of low-fat/high-added water meat products, increasing the value of reduced-lean trimmings. The objectives of this project were: to develop and characterize the functional properties of pork skin fat emulsion gels, to determine the combination of pork skin, reduced-lean trim and added water that optimizes the functionality of reduced-lean trimmings and to determine how selected pork skin fat emulsion gels would impact water binding, texture and sensory properties of low-fat/high-added-water bologna.

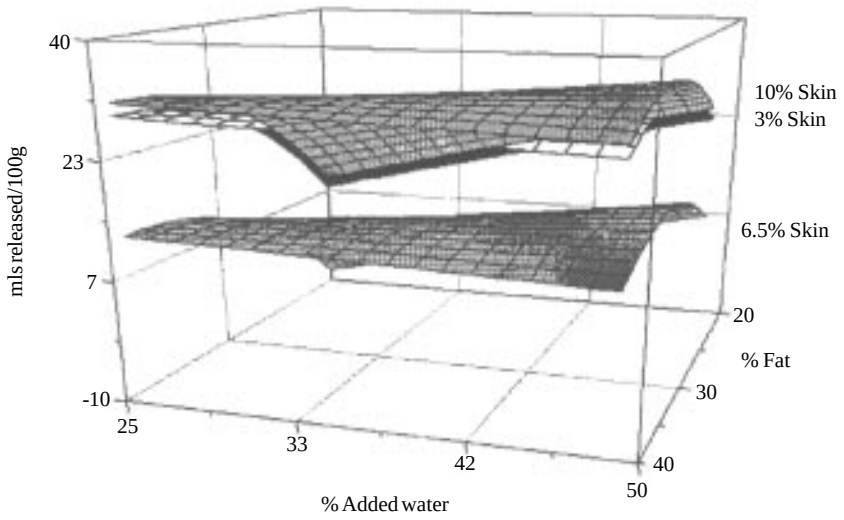

Figure 1. Predicted emulsion stability: total liquids released/100g.

Materials and Methods

Fat Emulsion Gel Characterization and Optimization

A 2^3 face-cube response surface experimental design determined combinations of pork skin (3 percent, 6.5 percent and 10 percent), AW (25 percent, 37.5 percent, and 50 percent) and reduced-lean pork trimmings (20 percent, 30 percent and 40 percent final fat content). Flaked pork skin and water were chopped in a steam-jacketed bowl chopper and heated to 160°F. After cooling the pork skin mixture below 85°F, reduced-lean pork trimmings and salt (4 percent) were added. The batter was chopped to an end point temperature of 105°F and samples collected for proximate composition, pH, hydration (raw batter water-binding ability), emulsion stability (water- and fat-binding ability during simulated thermal processing) and collagen content.

The objective texture attributes of fracturability, hardness, cohesiveness, springiness, chewiness and gumminess were determined by crushing three 1.5" x 1.5" x 0.5" samples to 25 percent of original height two times on a flat surface plate. Hardness measures the force it takes to crush the sample while springiness is a measurement of how much the sample springs back after being crushed one time. Gumminess and chewiness are calculated from values determined for hardness, springiness and cohesiveness. Lee-Kramer shear was conducted on five 2" x 2" x 0.5" samples from each treatment and the peak force to shear and total energy to shear were calculated.

Fat Emulsion Gel Incorporation

It was determined FG should be formulated with 6 percent skin for optimal functionality and at least 30 percent fat to utilize more reduced-lean trimmings. Pork skin FG with the best emulsion stability [30 percent fat, 25 percent added water (AW)] or best hydration/softest texture (30 percent fat, 50 percent AW) properties and the most economical FG (40 percent fat, 50 percent AW) were incorporated into low-fat/high-added-water bologna. The experiment was conducted using a randomized complete block design and replicated three times.

Each FG was mixed for five minutes with ground pork trimmings (96 percent lean) and water to contain 10 percent fat and 30 percent AW and then passed through an emulsifier. Two control pork bologna formulations (without FG) contained 10 percent fat/30 percent AW or 30 percent fat/10 percent AW and were manufactured identically to bologna containing FG. Analysis of raw bologna batter included back extrusion, proximate composition, collagen content and emulsion stability. Bologna was thermally processed to 150°F and cook yield was determined. Additional analyses included purge (meat juice accumulated in bag after storing for 21 or 42 days), expressible moisture (moisture expressed from meat using centrifugal force at zero, 21 and 42 days), objective color (lightness, redness, yellowness, cured color intensity) using a Hunter Labscan Colorimeter and compression and Lee Kramer shear using an Instron.

An eight-member, experienced panel was used to evaluate the bologna for appearance, texture and flavor. The texture of bologna samples was evaluated for resistance to bite (force required to bite through sample), springy/rubbery (amount sample springs back to original shape when compressed with molars), cohesiveness (amount that sample sticks together and forms a ball in mouth), adhesiveness (amount that sample sticks to teeth and roof of mouth) and juiciness.

Results and Discussion

Fat Emulsion Gel Characterization and Optimization

Response surface regression analysis used for pork skin levels of 3, 6.5 and 10 percent predicted optimal emulsion stability (lowest ml fat and

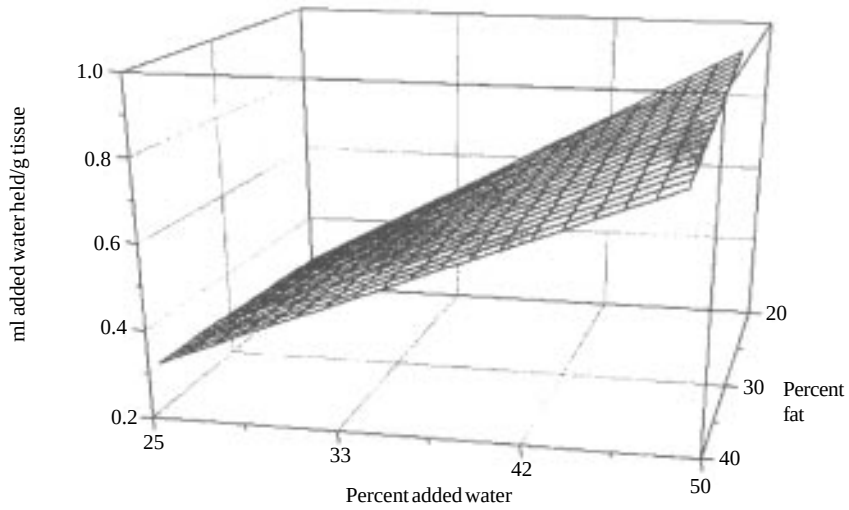

Figure 2. Predicated fat emulsion get hydration.

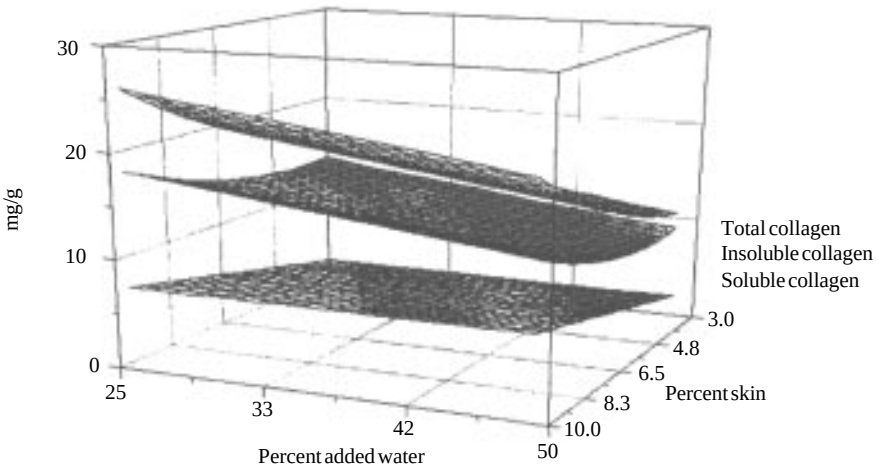

Figure 3. Collagen content in fat emulsion gels.

gel water released/100g) in FG occurred with 6 percent pork skin. Emulsion stability decreased as fat level and AW increased to 40 and 50 percent, respectively (Figure 1). Predicted hydration values (water binding capacity) of raw FG batter increased linearly ($P<0.05$) from 0.28g water held/g tissue at 25 percent AW to 0.96g water held/g tissue at 50 percent AW (Figure 2).

Soluble collagen, insoluble collagen and total collagen concentration of FG increased ($P<0.05$) as percent pork skin increased and total and insoluble collagen values decreased ($P<0.05$) as AW increased (Figure 3). The cohesiveness of FG decreased as percent pork skin increased ($P<0.05$). FG soluble collagen was correlated ($P<0.05$) with cohesiveness ($r=-0.51$). Some FG containing 6.5 percent pork skin fractured (an indication of brittleness) and all FG containing 10 percent pork skin fractured. Less cohesive samples are usually more brittle.

Cohesiveness partly explains how skin, fat and AW levels affect the properties of fat emulsion gels. Although soluble collagen protein from pork skin can bind water and emulsify fat, too much soluble collagen causes fat emulsion gels to break down. Soluble collagen does not have the water-binding and fat-emulsification capacity of the salt-soluble meat proteins, myosin and actin. The lower cohesion values in FG with more pork skin and more soluble collagen were reflected in the emulsion stability test where FG with more than 5 to 6 percent pork skin were less functional.

Fat Emulsion Gel Incorporation

Bologna containing selected FG required more force to fracture and were harder ($P<0.05$) than control low-fat/high-added-water bologna but similar ($P>0.05$) to the full-fat control (Table 1), all desirable responses. Bologna containing FG were chewier than the full-fat control because they were more cohesive, and the bologna containing the "best emulsion stability" FG (FG released least amount of fluids during simulated cooking) was chewier than the low-fat/high-added-water control because they were harder. Sensory panelists found incorporating FG made the hardness of low-fat/high-added water bologna more like the full fat control, which supported objective texture measurements. Bologna containing the "most economical" (FG primarily fat, water and skin, all inexpensive ingredients) or "best hydration" (FG held the most water) FG had more ($P<0.05$) resistance to bite and was more springy than the low-fat/high-added-water control, but similar to the full-fat control. As previously mentioned, low-fat/high-added-water bologna is often softer than full-fat bologna (as was the case in this study), and adding FG to low-fat/high-added water bologna made the hardness much more like that of a full-fat bologna.

Incorporation of FG in bologna did not alter ($P>0.05$) sensory panel juiciness scores of low-fat/high-added-water bologna. The bologna made with the "best emulsion stability" FG provided a more "coated" mouth feel than the bologna made with the "most economical" FG.

(Continued on next page)

Table 1. Least square means for texture profile analysis attributes, Lee-Kramer shear and taste panel scores for bologna manufactured with or without pork skin, fat emulsion gels.

	Best emulsion stability[x]	Best hydration[y]	Most economical[z]	10% fat/ 30% AW	30% fat/ 10% AW	OC[d]
Compression						
Fracturability (N/g)	19.52	21.44	20.13	17.45	19.68	❖
Hardness (N/g)	29.28	27.46	26.48	24.42	27.50	❖
Cohesiveness	0.19[b]	0.20[b]	0.19[b]	0.20[b]	0.13[a]	⌘
Springiness (mm)	5.91[a]	5.80[a]	5.75[a]	5.71[a]	6.54b	⌘
Gumminess (N/g)	5.67[b]	5.48[b]	5.04[b]	4.88[b]	3.68[a]	⌘
Chewiness (J/g)	0.033[c]	0.032[bc]	0.029[b]	0.028[ab]	0.024[a]	⌘
Kramer shear						
Peak force (N/g)	16.90	17.06	17.45	17.52	19.08	⌘
Energy (J/g)	0.109[a]	0.112[a]	0.113[ab]	0.121[bc]	0.127[c]	⌘❖
Panel texture[f]						
Resistance to bite[g]	6.94[a]	10.05[b]	9.74[b]	6.87[a]	8.59[b]	❖
Springiness[g]	6.38[a]	9.54[c]	8.92[bc]	6.92[a]	7.70[ab]	❖
Cohesiveness[g]	8.66	7.97	8.18	8.05	9.89	⌘
Adhesiveness[g]	7.28[b]	6.87[ab]	5.62[a]	6.62[ab]	8.34[c]	⌘
Panel flavor[f]						
Juiciness[h]	8.60[b]	8.59[b]	8.98[b]	8.77[b]	7.05[a]	⌘
Bologna flavor[g]	8.93	9.07	9.26	9.33	8.88	
Saltiness[g]	7.28	7.18	7.63	7.19	7.13	
Panel aftertaste/feel[f]						
Bologna flavor[g]	7.47	8.07	8.49	7.99	8.13	
Mouthcoat[i]	7.41[b]	6.72[ab]	5.92[a]	6.77[ab]	8.79[b]	⌘

⌘The average of the three bolognamade with a fat emulsion vs. the high fat control; P<0.05.
❖The average of the three bologna made with a fat emulsion versus the low-fat, high-added-water control; P<0.05.
[abc]Means in the same row having different superscripts are significantly different (P<0.05).
[d]OC = orthogonal contrasts.
[f]All attributes rated on a 15 cm scale.
[g]1=lacking; 15=intense.
[h]1=dry; 15=moist.
[i]1=clean; 15=coated.
[x]10% fat/30% AW bologna + best emulsion stability fat emulsion gel.
[y]10% fat/30% AW bologna + best hydration fat emulsion gel.
[z]10% fat/30% AW bologna + most economical fat emulsion gel.

Table 2. Least square means for objective and sensory appearance measurements of bologna manufactured with or without pork skin, fat emulsion gels.

	Best emulsion stability[x]	Best hydration[y]	Most economical[z]	10% fat/ 30% AW	10% fat/ 10% AW	OC[e]
L*	74.40[c]	71.67[b]	71.44[ab]	69.77[a]	73.94[c]	⌘❖
a*	16.77[a]	18.42[b]	18.41[b]	18.50[b]	17.01[a]	⌘❖
b*	14.97[a]	15.15[a]	14.93[a]	15.16[a]	15.64[b]	⌘
Cured meat color	1.75[a]	1.89[b]	1.90[b]	1.92[b]	1.75[a]	⌘❖
a/b	2.49[a]	2.73[b]	2.76[b]	2.74[b]	2.43[a]	⌘
Panel appearance[h]						
Color intensity[i]	5.57[b]	7.36[c]	8.45[cd]	9.03[d]	2.40[a]	⌘❖
Color uniformity[j]	9.37	9.39	8.46	9.35	8.72	⌘❖

⌘The average of the three bologna made with a fat emulsion vs. the high fat control; P<0.05.
❖The average of the three bologna made with a fat emulsion versus the low-fat, high-added-water control; P<0.05.
[abcd]Means in the same row having different superscripts are significantly different (P<0.05)
[e]OC=orthogonal contrasts.
[h]All attributes rated on a 15 cm scale.
[i]1=pale; 15=dark.
[j]1=uneven; 15=even.
[x]10% fat/30% AW bologna + best emulsion stability fat emulsion gel.
[y]10% fat/30% AW bologna + best hydration fat emulsion gel.
[z]10% fat/30% AW bologna + most economical fat emulsion gel.

However, FG incorporation was unable (P>0.05) to provide the same "coated" mouth feel associated with a full-fat bologna (Table 1).

Sensory panels found the average color intensity of low-fat/high-added-water bologna with FG was lighter (P<0.05) than the low-fat/high-added-water control, but not as light (P<0.05) as the full-fat control (Table 2). L* values (lightness) followed a similar pattern. The bologna containing the "best emulsion stability" FG was similar (P>0.05) to the full-fat control for all color measurements except b* values (yellow/blue). Incorporating the "best emulsion stability" FG into a low-fat/high-added-water bologna resulted in a bologna that looked very similar to a full-fat pork bologna.

Addition of FG to bologna had similar cook yield, purge and emulsion stability properties when compared to the low-fat/high-added-water control (Table 3). However, there was a trend (P=0.08) for the low-fat/high-added-water control to have poorer emulsion stability than bologna containing FG, which may indicate incorporation of FG into comminuted meats at higher levels could provide processing yield advantages.

Conclusions

Pork skin and reduced-lean pork trimmings have low economic value. They were successfully incorporated into low-fat meat products by creating a fat emulsion gel. The textural and functional properties of FG were characterized over a range of fat and AW levels and functional properties of FG for use as a raw material were optimized using 6 percent pork skin. Higher levels of pork skin resulted in FG that were less cohesive, perhaps because soluble collagen levels were too high.

Use of FG as a raw material improved texture and color by decreasing the softness and darkness associated with low-fat/high-added-water bologna. Low-fat/high-added-water bologna made with FG was more like

Table 3. Least square means for processing yields and raw bologna batter characteristics of bologna manufactured with or without pork skin, fat emulsion gels.

	Best emulsion stability[g]	Best hydration[h]	Most economical[i]	10% fat/ 30% AW	30% fat/ 10% AW	OC[e]
Cook yield (%)	89.47[a]	90.27[a]	90.20[a]	90.00[a]	94.49[b]	⌘
Chill yield (%)	87.77[a]	88.17[a]	88.23[a]	87.87[a]	91.67[b]	⌘
Purge (%)	2.35[b]	2.36[b]	2.47[b]	2.55[b]	0.92[b]	⌘
Emulsion stability						
Total fluids (ml/100g)	0.17	0.14	O.31	0.58	0.20	❖=.08
Fat (ml/100g)	0.00	0.01	0.00	0.03	0.01	
Gel water (m/100g)	0.17	0.13	0.31	0.55	0.19	❖=.08

⌘The average of the three bologna made with a fat emulsion vs. the high-fat control; P<0.05.
❖The average of the three bologna made with a fat emulsion versus the low-fat/high-added-water control; P<0.05.
[ab]Means in the same column having different superscripts are significantly different (P<0.05).
[e]OC=orthogonal contrasts.
[g]10% fat/30% AW bologna + best emulsion stability fat emulsion gel.
[h]10% fat/30% AW bologna + best hydration fat emulsion gel.
[i]10% fat/30% AW bologna + most economical fat emulsion gel.

a full-fat pork bologna than the low-fat/high-added-water control bologna. Sensory panelists found bologna made with FG were firmer and lighter in color. The value of reduced-lean trimmings can be increased by incorporating pork skin fat emulsion gels into comminuted meat products.

[1]Timothy D. Schnell is a graduate student and Roger W. Mandigo is a professor in the Department of Animal Science.

Impact of Drinker Type on Pig Performance, Water Use and Manure Production

Michael C. Brumm
Jill Heemstra[1]

Summary and Implications

A summer experiment was conducted to examine the impact of drinker design on pig performance, water use and manure volume. Pigs with access to Drik-O-Mat® bowl drinkers had similar daily gains, lower feed intake and improved feed conversion compared to pigs with access to a WaterSwing® nipple drinker. Water use was reduced 24.8 percent for the bowl versus swing drinkers. Manure volume was reduced 21.6 percent for the bowl versus swing drinker. The difference in manure volume is most likely due to a reduction in water wastage. Selection of drinker devices must include consideration of the manure system design and the need for wasted water for the manure system to function correctly.

Introduction

Research results regarding the impact of a wet/dry feeder and swinging nipple drinker on pig performance, water disappearance and manure volume were reported in the 1997 Nebraska Swine Report. That research demonstrated feeder and drinker selection can impact water usage and manure production. The following experiment was a continuation of that research and compared a bowl drinker with the swinging nipple drinker.

Methods

Pigs were housed in two similar mechanically ventilated, partially slatted finishing barns at the University of Nebraska's Haskell Agricultural Laboratory at Concord. Each barn had six 12 ft x 15 ft pens with 50 percent of the pen area slatted. There were 20 pigs per pen at the start of the experiment. Pen size was not adjusted in the event of pig death or removal for poor performance.

The manure system in each barn was a shallow pit drained periodically into a lagoon (i.e., pull-plug system). The pens on each side of a center aisle had a common pit and pull-plug system and drinkers were assigned to either the north or south side of the aisle within a barn, so manure production could be estimated from manure depth in the common pit for each feeder or waterer type.

Water disappearance (animal intake and waste) was measured for each drinker type in each barn by water meters installed in the water delivery line corresponding to the manure pit location. Manure production was estimated by recording the manure depth in each pit prior to each draining.

All diets were corn-soybean meal based (meal form) with 5 percent added fat and formulated to meet the University of Nebraska recommendations for pigs of high-lean gain potential. Diets were switched on the week pigs in individual pens averaged 80, 130 and 190 pounds. Individually identified pigs were removed for slaughter on the week they weighed at least 250 pounds.

A single Drik-O-Mat® bowl drinker was fastened to the pen partition over the slatted portion of the pen 32 inches from the rear of the 15-foot-deep pen. The lip of the bowl was 10 inches from the floor. The WaterSwing® drinker consisted of two nipple drinkers attached to a delivery pipe which was suspended from a chain anchored to

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the ceiling in the middle of pig pen. The swinging nipple was adjusted for height as necessary to provide 2 to 4 inches of clearance between the shoulder of the pigs (while standing) and the bottom of the drinker.

Drippers were utilized for summer heat relief with dripping initiated at 80°F. Each pen on both drinker types had one, four-hole Farmweld brand wean-to-finish feeder installed perpendicular to the aisle on the solid portion of the pen.

Results and Discussion

The bowl drinkers were originally installed 10 inches above the floor per instructions from the distributor. However, the lightest replication of pigs averaged 34 pounds at arrival. By day five after arrival, it was evident pigs were not consuming adequate water. All bowl drinkers were lowered to 7 inches and remained at this height until 21 days after arrival.

On day 82, an outbreak of swine influenza was diagnosed in all facilities at the swine research unit. Under veterinary direction, pigs were water-medicated with sulfadimethoxine for four days and medication use was recorded by drinker type (Table 1). Water medication use and resultant medication costs per pig was less ($P < .01$) for pigs on the bowl drinkers versus the swinging drinker. An interesting observation was that water usage per-pig per-day remained relatively constant during the four-day medication period when compared to the overall 17-day period during which the medication was provided for pigs on the bowl drinkers. However, water usage was .4-.5 gal/pig/day higher during the medication period when compared to the overall 17-day period for the pigs on the swinging drinkers. The increased usage (assumed to be wastage since no difference in pig performance was measured) is due possibly to the pigs' aversion to the medication and the nipple drinkers allowed for more wastage to occur.

There was no difference of drinker type on uniformity of pig weight within a pen as measured by the coefficient of variation of within pen weights when the first pig in a pen was marketed (Table 2). There was no effect of drinker type on average daily gain. Pigs on the bowl drinkers ate less feed and had an improved feed conversion efficiency compared to the pigs on the swing drinker. The number of pigs that died or were removed from the experiment was not affected by waterer type.

Pigs on the cup drinkers used less water than pigs on the swing drinkers (Table 2). Overall water use was 24.8 percent less for the cups versus swings. The water-to-feed ratio of 1.89:1 for the bowl drinkers was less than the 2:1 ratio often considered a minimum in many nutrition text books. However, it is similar to the ratio reported in a previous study with wet/dry feeders.

While the experiment was designed to estimate manure production for each drinker type, repeated problems with one facility resulted in only one estimate of manure production for each drinker type. Our best estimate is a 22 percent reduction in manure volume for the cup versus swing drinker. No samples were collected for dry matter analysis, but manure from the collection pits under the cup drinkers was observed to flow poorly when the pit plugs were pulled. The eight-inch drain line completely plugged and required mechanical cleanout in one instance. No such problems were encountered with manure from the collection pits under the swing drinkers.

Table 1. Effect of drinker type on water medication usage and costs.

	Drinker type		
Item	Bowl	Swing	P value
Water use, gal/pig/d			
Aug 22 to Sept 9	1.05	1.55	<.01
Aug 27 to Aug 30[a]	.99	1.96	<.01
Drug cost, $/pig[a]	$0.082	$0.162	<.01

[a]Albon 12.5% solution @ $42.25/gal mixed to deliver 30 gm sulfadimethoxine per 128 gal/water.

Table 2. Effect of drinker type on pig performance.

	Drinker type		
Item	Bowl	Swing	P value
No. pens	6	6	
Pig weight, lb			
Initial	38.3	38.5	
Final	251.2	253.8	
CV at first removal	8.8	8.8	>.15
Average daily gain, lb	1.8	1.83	>.15
Average daily feed, lb	4.51	4.67	<.01
Feel/gain	2.49	2.55	<.1
Dead/removed, no.	1	3	>.15
Water, gallons/pig/d	1.00	1.33	<.06
Water/feed, lb/lb	1.89	2.41	<.01
Manure production, gallons/pig/d[a]	.87	1.11	

[a]Not statistically analyzed due to only one observation per drinker type.

Conclusion

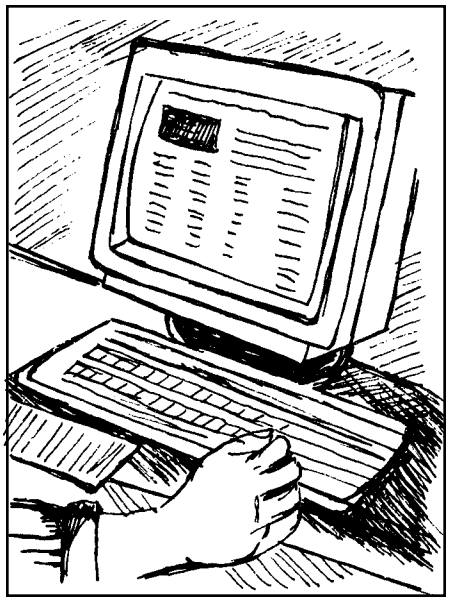
The installation of the Drik-O-Mat® cup drinkers resulted in a 24.8 percent reduction in water usage and a 50 percent reduction in water medication expense compared to WaterSwing® nipple drinkers. However, if the manure system requires wasted water for dilution purposes, selection of a cup drinker similar to the one tested in this experiment may create management concerns making their use inadvisable.

[1]Michael C. Brumm is professor and Extension swine specialist and Jill Heemstra was research technologist at the Northeast Research and Extension Center, Concord, Nebr.

Explanation of Statistics Used in This Report

Pigs treated alike vary in performance, due to their different genetic makeup and to environmental effects we cannot completely control. When a group of pigs is randomly allotted to treatments it is nearly impossible to get an "equal" group of pigs on each treatment. The natural variability among pigs and the number of pigs per treatment determine the expected variation among treatment groups due to random sampling.

At the end of an experiment, the researcher must decide whether observed treatment differences are due to "real" effects of the treatments or to random differences due to the sample of pigs assigned to each treatment. Statistics are a tool used to aid in this decision. Statistics are used to calculate the probability that observed differences between treatments were caused by the luck of the draw when pigs were assigned to treatments. The lower this probability, the greater confidence we have that "real" treatment effects exist. In fact, when this probability is less than .05 (denoted **P < .05** in the articles), there is less than a 5 percent chance (less than 1 in 20) that observed treatment differences were due to random sampling. In these instances we conclude that the treatment effects are "real" and caused different performance for pigs on each treatment. Bear in mind, however, if the researcher obtained this result in each of 100 experiments, five differences would be declared to be "real" when they were really due to chance. Sometimes the probability value calculated from a statistical analysis is P < .01. This indicates the chance that



random sampling of pigs caused observed treatment differences is less than 1 in 100. Evidence for real treatment differences, then, is very strong.

It is common to say differences are significant when P <.05 and highly significant when P < .01. However, P values can range anywhere between 0 and 1. Some researchers say there is a tendency for real treatment differences to exist when the value of P is between .05 and .10. Tendency is used because we are not as confident the differences are real. The chance that random sampling caused the observed differences is between 1 in 10 and 1 in 20.

Sometimes, researchers report **standard errors of means (SEM)** or **standard errors (SE)**. These are calculated from the measure of variability and the number of pigs in the treatment. A treatment mean may be given as 11 $\pm$ .8. The 11 is the mean and the .8 is the SEM. The SEM or SE is added and subtracted from the treatment mean to give a range. If the same treatments were applied to an unlimited number of animals the probability is .68 (1 = complete certainty) that their mean would be in this range. In the example the range is 10.2 to 11.8.

Some researchers report **linear (L)** and **quadratic (Q)** responses to treatments. These effects are tested when the researcher used increasing increments of a factor as treatments. Examples are increasing amounts of dietary lysine or energy, or increasing ages or weights when measurements are made. The L and Q terms describe the shape of a line drawn to describe treatment means. A straight line is linear and a curved line is quadratic. For example, if finishing pigs were fed diets containing .6, .7 and .8 percent lysine gained 1.6, 1.8 and 2 pounds/day, respectively, we would describe the response to lysine as linear. In contrast, if the daily gains were 1.6, 1.8 and 1.8 pounds/day, the response to increasing dietary lysine would be quadratic. Probabilities for tests of these effects have the same interpretation as described above. Probabilities always measure the chance that random sampling caused the observed response. Therefore, if P < .01 for the Q effect was found, there is less than a 1 percent chance that random differences between pigs on the treatments caused the observed response.