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EC94-219 1995 Nebraska Swine Report

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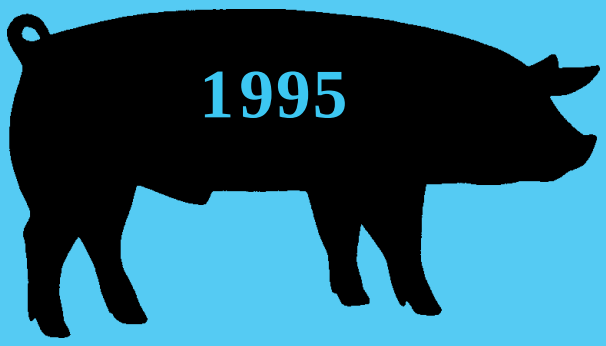

NEBRASKA SWINE REPORT

- **Reproduction**
- **Breeding**
- **Health**
- **Nutrition**
- **Economics**
- **Housing**

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

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Agricultural Research Division
Institute of Agriculture and Natural Resources
University of Nebraska-Lincoln

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The 1995 Nebraska Swine Report was compiled by Rodger K. Johnson, Professor, Animal Science, Department of Animal Science.

Cover Photo:

Pictured on the cover photo are examples of animals used in the UNL Swine Research program. The litter represents selection for sow reproductive traits, the finishing pigs represent the nutritional and meat science trials to improve lean growth, and the mouse and pig illustrate how laboratory animals are used in animal health research.

How Long Does Standing Estrus Last After Initial Boar Exposure When Heat Checking?

Donald G. Levis
Paul H. Hemsworth[1]

A series of experiments in Australia have clearly shown that the percentage of estrous gilts displaying the standing-response to the back-pressure test is reduced when gilts are housed adjacent to boars (Figure 1).

The decrease in efficiency of estrous detection is thought to occur because gilts become accustomed (habituated) to auditory and olfactory stimuli of the boar and are then less responsive to boar stimuli at the time of estrous detection. This result may occur because gilts are habituated or are refractory (females are in estrous but will not stand) to boar stimuli at the time of estrous detection.

The following experiment was conducted to test the hypothesis that estrous gilts become refractory to boar stimuli after initially exhibiting standing estrus.

Materials and Methods

Seventeen ovariectomized gilts were induced into estrus by intramuscularly injecting .8 mg estradiol benzoate (EB) on two consecutive days. Starting four days after the first EB injection, gilts were individually taken to a breeding facility and observed for standing estrus by applying pressure to the gilts back while boars were present. Before pressure was applied on the gilt's back, each gilt was carefully positioned so she had excellent head-to-head contact with a boar. If a gilt stood for a full 10 seconds, she was recorded as being in standing estrus. Gilts did not have boar contact before entering the breeding facility.

The breeding facility had two breeding pens. Six boars (three boars per side) were penned facing and adjacent to each breeding pen. All 12 boars were known to be sexually aggressive before the experiment began.

Each gilt was observed for standing estrus in the first breeding pen at 0 (time of entry), 5, and 10 minutes after entry into the breeding facility. It was considered possible that the boars' courtship (chanting and chomping) may decline when continuously presented with the same gilt over a 21-minute period; therefore, each gilt was carefully moved (about 3 feet) through a gate into the adjacent breeding pen and observed for standing estrus at 11, 16, and 21 minutes after initial entry into the first breeding pen.

Gilts were heat-checked at 93 (Day 1-AM), 99 (Day 1-PM), 117 (Day 2-AM), and 123 hours (Day 2-PM) after the last EB injection. Gilts were housed in a separate building (3 to 4 gilts per pen) when not being heat-checked.

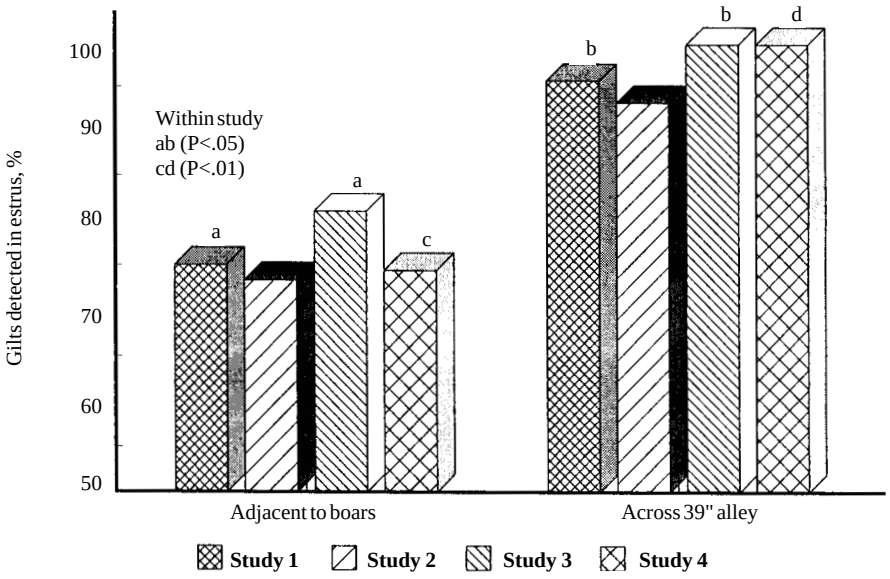

Figure 1. The effect of housing location on the efficiency of detecting estrus in gilts

Results

On Day 1, four gilts did not exhibit the standing response at the first observation during the AM evaluation, and two gilts did not exhibit the standing response at the first observation during the PM evaluation. Since the duration of standing estrus can not be measured in nonestrus females, the statistical analysis of data for Day 1-AM and Day 1-PM did not include nonestrus females.

The number of gilts that exhibited standing estrus at 0 minutes was 13, 15, 17 and 17 for Day 1-AM, Day 1-PM, Day 2-AM, and Day 2-PM, respectively.

The Chi-square analysis showed a significant effect for day of evaluation ($\chi^2 = 4.87$, $P < .03$) and time of evaluation ($\chi^2 = 19.29$, $P < .002$). The proportion of gilts standing across time was higher on Day 1 than Day 2 (Figure 2). The proportion of gilts found in standing estrus on Day 1-AM started to

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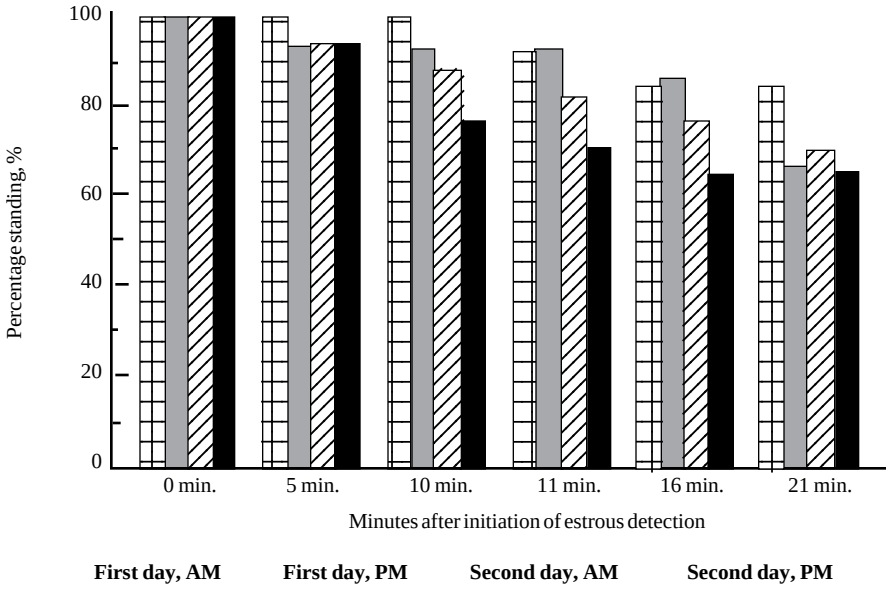

Figure 2. Proportion of gilts in standing estrus.

decrease at the 11-minute observation time, 84.6 % of the gilts were found in standing estrus at the 21-minute observation time.

The proportion of gilts exhibiting the standing response on Day 1-PM was 93.3 % at observation times of 5, 10, and 11 minutes and 66.7 % at the 21-minute observation time. The proportion of gilts found in standing estrus on Day 2-AM decreased linearly to 70.6 % at the 21-minute observation time. The proportion of gilts in standing estrus on Day 2-PM decreased to 64.7 % at the 16- and 21-minute observation times.

Conclusions and Implications

The results of this study are interpreted to mean that estrous gilts become refractory to boar stimuli. Therefore, when estrous gilts show an initial standing response to boars, they should be mated within approximately 10 minutes or some of the females may become refractory to boar stimuli. It is not known whether the duration of time before estrous females become refractory after receiving boar stimuli is different for recently weaned sows, females having continuous boar contact, or when females receive physical contact from a boar during mating.

[1]Donald G. Levis is a Professor and Extension Swine Specialist, Department of Animal Science, Lincoln, NE; Paul H. Hemsworth is a Senior Scientist, Victorian Institute of Animal Science, Attwood, Victoria, Australia. Research was conducted in Australia.

Elevation of Plasma FSH with a Low Level of FSH-P During the Early to Mid Follicular Phase Blocks the Loss of Greater Numbers of Medium Follicles in Control Line Gilts Compared to Gilts Selected for High Ovulation Rate

Hui-Wen Yen
Steve Christian
Dwane R. Zimmerman[1]

The number of follicles ovulated (ovulation rate) at estrus is an important determinant of litter size in the pig because it sets the upper limit for litter size.

Ovulation rate is a moderately heritable trait in pigs (h^2 = 40%). Gilts selected for high ovulation rate (Relax Select, RS line) in the University of Nebraska Gene Pool population ovulated about 3.5 more follicles than randomly selected Control (C) line gilts after nine generations of selection. This difference continues to be maintained after many generations of random selection following the end of deliberate selection.

Evaluation of the pattern of follicular development showed that RS gilts maintain a larger pool of 3 to 6.9 mm follicles than C gilts during the mid to late follicular phase of the estrous cycle. Also, a greater proportion of the 5 to 6.9 mm follicles were healthier in RS than C gilts during this period.

Large preovulatory follicles were slower to develop in RS gilts and it was not until late in the follicular phase that RS gilts developed the number of large preovulatory follicles needed to achieve their advantage in ovulation rate. Other studies showed that RS gilts maintain elevated concentrations of follicle-stimulating hormone (FSH), but not

luteinizing hormone (LH), during the late luteal and early follicular phases of the estrous cycle (days 12 to 14). The elevated concentrations of FSH in RS gilts during the late luteal and early follicular phases may be involved with the maintenance of a larger pool of healthy 5 to 6.9 mm follicles from which preovulatory follicles are selected.

Therefore, the present study was conducted to: 1) further characterize relationships between development and maturation of follicles and concentrations of gonadotropic and gonadal hormones in RS and C line gilts during the early to mid follicular phase of the estrous cycle; and 2) determine whether FSH therapy (treatment with FSH-P, a commercially available porcine FSH preparation) during the early to mid follicular phase of the estrous cycle will prevent the loss of medium follicles and reverse the pattern of development and/or maintenance of fewer medium follicles in C than RS gilts during the mid follicular phase.

Materials and Methods

Thirty-nine RS and 40 C line gilts from the University of Nebraska Gene Pool herd were assigned randomly within sire to a replicated experiment that evaluated follicle development and maturation at two intervals (24 or 48 hour) after initiation of FSH-P treatment. Gilts from the RS and C lines represented the progeny of 13 and 14 sires, respectively. The gilts were 9 to 11 months of age and weighed between 100 and 150 kg when evaluated. They had experienced two or more estrous cycles before assignment to experiment.

Two injections of $PGF_{2\alpha}$ (10 mg Lutalyse) were given at 12 h intervals to all gilts on day 13 of the estrous cycle to induce luteolysis and initiate the start of the follicular phase on the same day. FSH-P treatment started 36 hours after first $PGF_{2\alpha}$. Gilts received 1.5 Armour Units (AU) of FSH-P at 12 hour intervals over 1 or 2 days until ovariectomy (OVX). Blood samples were collected at 12 hour intervals from day 13 to OVX and assayed for concentrations of FSH, LH, estradiol and progesterone.

At ovariectomy, the numbers of corpora albicantia 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 and recorded as follows: medium-1 (M1F, 3 to 4.9 mm), medium-2 (M2F, 5 to 6.9 mm) and large (LF, equal or above 7 mm). Follicle numbers for the different size categories were not normally distributed, so the data concerning follicle numbers were converted to relative percentage for each gilt (dividing numbers of follicles in a given size category by the total number of follicles in all three size categories) before the data were analyzed statistically.

The follicular fluid was assayed for estradiol (E) and the concentration of E was used to assess the health status of individual follicles. Follicles with E greater than 100 ng/mL were classified as healthy (estrogen-active) and follicles with E less than 100 ng/mL as atretic or degenerate (estrogen inactive).

Results and Discussion

Overall, RS gilts ovulated about two more ova than C gilts at the pretreatment estrus (14.3 vs 12.3, $p<.001$). The ovulation rate difference between lines was less than observed in earlier studies. Gilts in the present study were given only 3.5 lb. of diet per day whereas gilts in most of the earlier studies were "flushed" (fed 7 lb of diet per day) for 10 to 14 days before estrus to stimulate maximal expression of ovulation rate.

Gonadotropic and Gonadal Hormone Concentrations in Plasma during the Pretreatment Period

Relax Select gilts maintained higher ($p<.02$) concentrations of FSH during the pretreatment period but the advantage decreased between 12 and 36 hour after PGF_{2a} treatment (Figure 1). This confirmed previous findings that RS gilts maintain greater concentrations of FSH between day 12 and day 14 of the estrous cycle. Concentrations of LH did not differ between genetic lines, also confirming previous observations.

Estradiol concentrations increased over time in both lines but the increase tended to be greater in RS than C gilts between 12 and 24 hours (Line x Hour, $p<.07$). This resulted in higher concentrations of E in RS gilts at both 24 and

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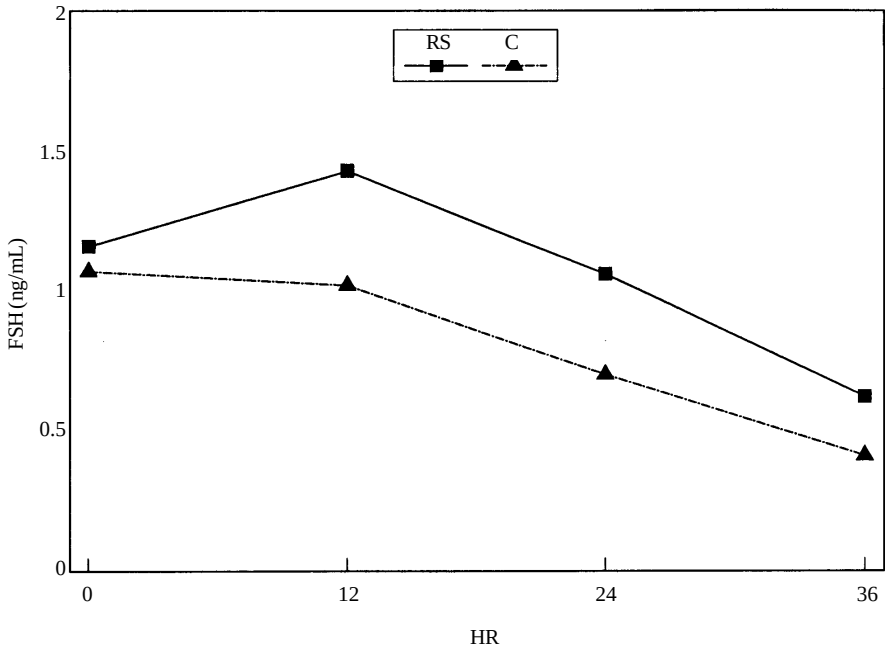

Figure 1. Mean concentrations of plasma FSH during the pretreatment period (0 to 36 h after $PGF_{2\alpha}$) as affected by genetic line and hour.

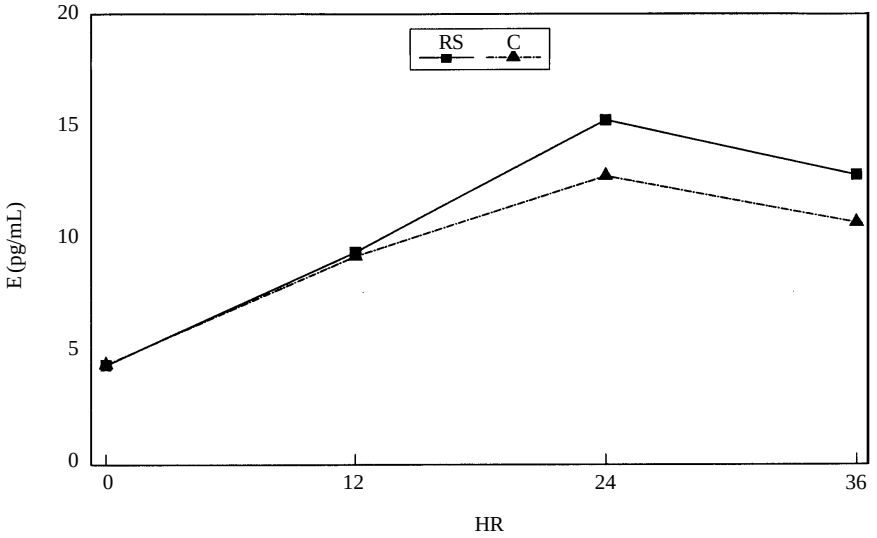

Figure 2. Mean concentrations of plasma estradiol (E) during the pretreatment period (0 to 36 h after $PGF_{2\alpha}$ injection) as affected by genetic line and hour.

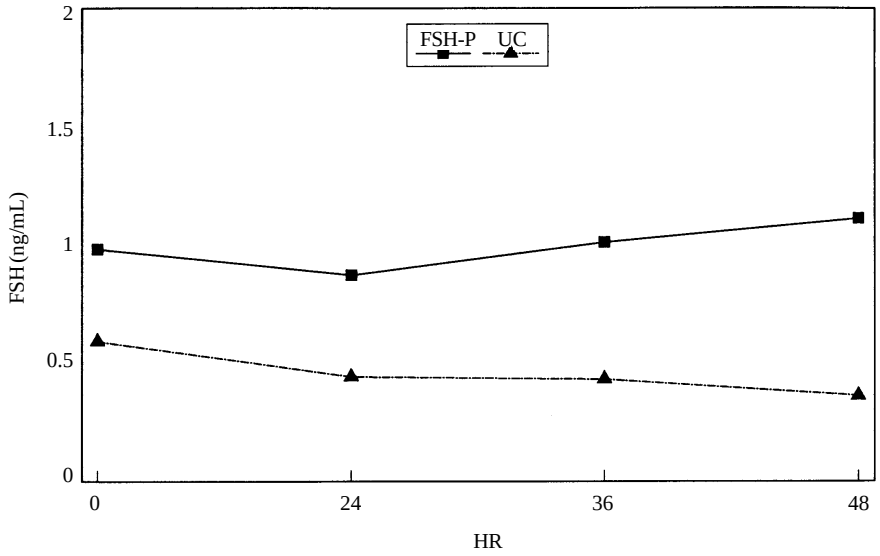

Figure 3. Mean concentrations of plasma FSH from12 to 48 h after first FSH-P injection as affected by treatment and hour.

36 hours after $PGF_{2\alpha}$ (Figure 2). The higher concentrations of plasma estradiol in RS gilts may have resulted from the higher concentrations of FSH observed during the early follicular phase in RS gilts.

Gonadotropic and Gonadal Hormone Concentrations in Plasma during the Treatment Period

Plasma FSH concentrations were elevated in FSH-P treated gilts over the entire treatment period but the difference in FSH levels increased with interval after first FSH-P treatment (Figure 3). This occurred because FSH levels tended downward over time in UC gilts while increasing after 24 hours in FSH-P treated gilts; FSH concentrations were more than 2-fold higher in FSH-P treated gilts than in UC gilts 48 hours after the first FSH-P treatment (1.1 vs .36 ng/mL at 48 hour, Figure 3).

Plasma LH concentrations declined over time in UC gilts of both genetic lines but tended to increase over time in FSH-P treated gilts. The different patterns of LH in UC and FSH-P treated gilts resulted in a .2 to .3 ng/mL elevation in LH at 36 and 48 hours in gilts treated with FSH-P. The increase in LH concentration probably reflects accumulation over time of the LH contamination in the FSH-P preparation.

Treatment of gilts with FSH-P stimulated elevated concentrations of estradiol during the treatment period. Estradiol levels increased 1.5-fold (16 to 40 pg/mL) in UC gilts compared to 2-fold (25 to 78 pg/mL) in FSH-P gilts between 12 and 48 hours after the first FSH-P treatment; concentration of estradiol was nearly twice as high in FSH-P treated gilts at 48 hour, when the maximum difference in estradiol concentration was observed (Figure 4). The higher concentrations of plasma estradiol in FSH-P treated gilts may be due to the development of greater numbers of estrogen-active (healthy) follicles in FSH-P treated gilts.

Number and Relative Percentage of Medium and Large Follicles

The data concerning numbers and relative percentage of medium and large follicles as affected by line, treatment and interval from first FSH-P treatment to OVX (24 vs 48 hour) are presented in Table 1 and Table 2, respectively.

The relative percentage of M1F (3 to 4.9 mm) was affected by treatment with FSH-P ($p<.01$) and interval to OVX (HR) after first FSH-P injection ($p<.01$) but not by genetic line. However, treatment with FSH-P had a differential effect on numbers of M1F at 24 and 48 hours after first FSH-P treatment.

Number of M1F increased in response to FSH-P at 24 hour but declined in response to FSH-P at 48 hour (Table 1). Thus, the loss of M1F between 24 and 48 hours was accelerated in FSH-P treated gilts as compared to UC gilts (Table 2).

The decrease in percentage of M1F between 24 and 48 hour after first FSH-P injection (60 and 84 hours after $PGF_{2\alpha}$ on day 13) may have resulted in part from growth of M1F into M2F. The greater loss of M1F may be due as well

to the elevated concentrations of LH described earlier. USDA researchers recently reported that administration of a highly purified porcine LH preparation increased the number of LF but decreased the number of small follicles by 70% by 72 hours after the first injection.

There was also a trend ($p<.08$) for an interaction between FSH-P treatment and genetic line. Mean numbers of M1F decreased in C while increasing in RS gilts in response to FSH-P. This suggests that RS gilts were more responsive to FSH-P. But it may have occurred in part because UC gilts from the RS line had lower numbers of M1F than UC gilts from C line at both 24 and 48 hours (60 and 84 hours post $PGF_{2\alpha}$); the numbers of M1F in FSH-P treated gilts were similar for the C and RS lines. The greater decline in number of M1F in C than RS gilts during this period verifies the results of a previous UNL study reported in the 1993 Swine Report.

The relative percentage of M2F declined as expected in UC gilts but increased in FSH-P treated gilts of both genetic lines between 24 and 48 hours (Table 2). Gilts treated with FSH-P had developed a greater number of M2F than UC gilts in both genetic lines at both 24 and 48 hours (Table 1). Purified porcine FSH (pFSH-B-1) has been reported by USDA researchers to increase numbers of small and/or medium follicles but not large follicles in pigs.

Untreated control gilts from the RS and C lines had similar percentages of M2F at 60 (C, 35.0 vs RS, 39.9%) and at 84 hours (C, 32.2% vs RS, 33.2%) post $PGF_{2\alpha}$. These results failed to confirm the findings of a previous study (1993 Swine Report) which reported a greater loss of M2F in C than RS gilts between day 3 and day 4 after $PGF_{2\alpha}$ treatment on day 13. However, follicle evaluation in the present study was done earlier in the follicular phase (day 2.5 and day 3.5 post $PGF_{2\alpha}$ on day 13). It is possible that the difference in follicle loss between day 3 and day 4 is not yet expressed at day 3.5 (84 hour post $PGF_{2\alpha}$) but still may be reflected in the percentage of M2F that are estrogen

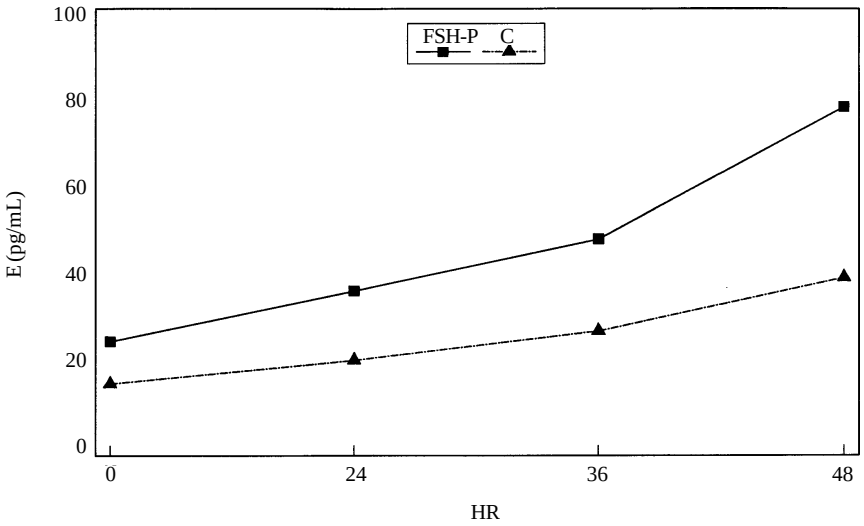

Figure 4. Mean concentrations of plasma estradiol (E) from 12 to 48 h after first FSH-P injection as affected by treatment and hour

Table 1. Mean number of medium and large follicles as affected by genetic line, treatment and hour after first FSH-P treatment

		M1F[a]		M2F[a]		LF[a]	
TRT	HR[c]	RS[e]	C[e]	RS	C	RS	C
UC[b]	24	16.0	21.5	11.0	11.8	1.1	1.0
FSH-P	24	25.9	23.1	17.5	16.4	1.8	1.8
UC	48	9.3	13.2	8.6	9.9	7.7	6.8
FSH-P	48	6.8[d]	5.0[d]	14.5	14.1	13.0	

[a]M1F = 3 to 4.9 mm, M2F = 5 to 6.9 mm, LF above 7 mm
[b]UC = untreated controls
[c]Hours to OVX after first FSH-P injection
[d]Zero values are included in mean
[e]RS, Relax Select line; C, Control line

Table 2. Relative percentage of medium and large follicles as affected by genetic line, treatment and hour after first FSH-P treatment.

		M1F[a]		M2F[a]		LF[a]	
TRT	HR[c]	RS[d]	C[d]	RS	C	RS	C
UC[b]	24	55.7	62.1	39.9	35.0	4.4	2.9
FSH-P	24	56.6	56.9	39.5	38.0	3.9	5.1
UC	48	34.0	43.6	33.2	32.2	32.9	24.2
FSH-P	48	17.6	14.3	41.7	42.6	40.7	43.2

[a]M1F = 3 to 4.9 mm, M2F = 5 to 6.9 mm, LF above 7 mm
[b]UC = untreated controls
[c]Hours to OVX after first FSH-P injection
[d]RS, Relax Select line; C, Control line

inactive (unhealthy). RS and C gilts showed similar patterns of development of M2F in response to FSH-P treatment (Tables 1 and 2).

The large follicle population was also influenced by treatment with FSH-P but, as with M1F and M2F, the effect differed at 24 and 48 hours after first FSH-P treatment. Large follicles accounted for about 4% of all follicles at 24 hours, regardless of treatment. However, LF developed more rapidly in FSH-P treated gilts of both genetic lines between 24 and 48 hours (Table 2). Mean numbers of LF were similar in UC and FSH-P treated gilts at 24 hour but were nearly 1-fold higher ($p<.01$) in

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Table 3. Mean estradiol concentrations (ng/mL) in follicular fluid from medium and large follicles.

		M1F[a]		M2F[a]		LF[a]	
TRT	HR[c]	RS[d]	C[d]	RS	C	RS	C
UC[b]	24	28.4	20.4	170.3	129.5	358.7	203.4
FSH-P	24	51.5	67.7	129.7	167.6	159.8	222.4
UC	48	7.2	6.8	135.0	117.1	279.7	261.4
FSH-P	48	93.0	19.0	226.5	210.2	335.5	287.6

[a]M1F = 3 to 4.9 mm, M2F = 5 to 6.9 mm, LF above 7 mm
[b]UC = untreated controls
[c]Hours to OVX after first FSH-P injection
[d]RS, Relax Select line; C, Control line

FSH-P treated gilts at 48 hour (Table 1). Numbers of LF developed to a similar level in response to FSH-P in C and RS gilts and numbers and relative percentages of LF were similar in both genetic lines on day 2.5 and day 3.5 post $PGF_{2\alpha}$ (Tables 1 and 2). The more rapid development of LF in C than RS gilts between day 3 and day 4 reported in a previous study (1993 Swine Report) was not evident between day 2.5 and day 3.5 in the present experiment. This difference may develop later in the follicular phase.

Estradiol (E) Concentrations in Follicular Fluid (FF)

Mean concentrations of E in FF are presented in Table 3. M1 follicles from gilts treated with FSH-P showed elevated ($p<.001$) concentrations of E, but the response differed between genetic lines and with interval to OVX after first FSH-P ($p<.01$). The E response to FSH-P was higher in C than RS gilts at 24 hour but the reverse was true at 48 hour. Concentrations of E declined in UC gilts in both lines between 24 and 48 hours but M1F from RS gilts continued to respond to FSH-P at 48 hour and achieved higher concentrations of E than occurred at 24 hour. In contrast, M1F from FSH-P treated C gilts at 48 hours showed less than a two-fold elevation in E above UC gilts and did not achieve the levels of E expressed by FSH-P treated C gilts at 24 hours (Table 3).

Treatment with FSH-P also increased E concentrations in M2F but the E responses differed at 24 and 48 hours after first treatment with FSH-P ($p<.003$). Estradiol concentrations in FF were comparable in UC and FSH-P treated gilts at 24 hour. But E concentrations in M2F had decreased slightly in UC gilts while increasing about 70% in FSH-P treated gilts at 48 hour (Table 3).

Treatment with FSH-P tended to exert a differential effect on E concentrations in FF from LF at 24 and 48 hours after first FSH-P treatment ($p<.07$). Estradiol concentrations were similar in FF from UC gilts at 24 and 48 hours but were suppressed at 24 hours and elevated at 48 hours in FSH-P treated gilts compared to UC gilts. The reasons for this tendency remain obscure.

The low concentration of E in FF of M1F from UC gilts at 24 and 48 hours does not reflect their inability to respond to gonadotropin. FSH-P treatment, with one exception, stimulated major elevations in E concentrations in FF at 24 and 48 hours after the first FSH-P injection. The exception was the M1F obtained from C gilts at 48 hour (84 hours post $PGF_{2\alpha}$). These follicles failed to increase their production of E in response to FSH-P. They may have lost their gonadotropin receptors and they may soon disappear from the ovaries. Histological evaluation may be required to assess atresia rate in M1F since all M1F are producing relatively low concentrations of E and are estrogen inactive.

Mean E concentrations in FF of M2F were similar to the levels reported during the same period in an earlier study conducted at UNL (1993 Swine Report). They found that concentrations of E in FF of M2F reached comparable levels (220 ng/mL) in C and RS gilts on day 3 and then either showed a small increase (RS line) or substantial decrease in E concentration (50% reduction, C line) to day 4. The decline in E concentration in FF from M2F in C gilts corresponded to the same time frame (day 3 to day 4) when major losses of M2F were occurring in C line gilts. The low E concentrations served as the basis for classifying the majority of these follicles atretic.

Health Status of the 5 to 6.9 mm Medium Follicles

Lower relative percentages and numbers of M2F were not observed in C line gilts on day 3.5 in the present study. However, these follicles may be undergoing biochemical changes leading to atresia and later loss from the surface of the ovaries. Therefore, the health status of M2F was assessed by classifying individual M2 follicles as healthy (estrogen-active, > 100 ng E/mL of FF) or atretic (estrogen inactive, < 100 ng E/mL of FF).

Untreated control gilts from the RS line had higher percentages of healthy M2F than C line gilts at both 60 (RS, 80% vs C, 69% healthy) and 84 hours (RS, 74% vs C, 52% healthy) post $PGF_{2\alpha}$ ($p<.01$). These differences are similar to those observed in an earlier study at 72 (RS, 86% vs C, 78% healthy) and 96 hours post $PGF_{2\alpha}$ (RS, 72% vs C, 50% healthy). Treatment with FSH-P lowered the percentage of healthy M2F in both genetic lines (RS, 68% vs C, 62%) at 24 hour (60 hours post $PGF_{2\alpha}$) but improved the percentage of healthy M2F (RS, 91% vs C, 92% healthy) at 48 hours after first FSH-P treatment (84 hours post $PGF_{2\alpha}$). Thus, enhanced gonadotropin concentration beginning at 48 hours (12 hours after first FSH-P injection) post $PGF_{2\alpha}$ was able to reverse the pattern of greater atresia of M2 follicles (5 to 6.9 mm) in C line gilts during the mid follicular phase of the estrous cycle. Since FSH-P treated RS and C line gilts have similar numbers of LF and healthy M2F at this stage (84 hours post $PGF_{2\alpha}$) of the follicular phase, it is probable that C line gilts will be able to continue to select follicles from the M2F pool. This should allow them to develop and ovulate comparable numbers of large preovulatory follicles as RS gilts. This will be evaluated in future studies.

[1]Hui-Wen Yen is a graduate student, Steve Christian is a Research Technologist and Dwane Zimmerman is a Professor in the Animal Science Department, University of Nebraska, Lincoln.

Improved Semen Characteristics in Boars Selected for Testis Size

Ying-Tsorn Huang
Rodger Johnson[1]

The practice of artificial insemination is increasing in swine herds. There is considerable variation among boars in age when semen can be collected, volume of semen, and sperm concentration, motility of sperm cells, and frequency of abnormalities in semen. Selection of boars has been for performance traits such as growth rate and backfat thickness and female reproductive traits such as size and weight of litters of dams and other female relatives.

Little selection for male reproductive traits has been practiced. However, selection practices that result in boars with greater quantities of high quality semen would improve the efficiency of artificial insemination and be beneficial to the industry.

Testis size is correlated with daily sperm production and with total sperm numbers in the epididymis in several species, including swine. At Nebraska, an experiment was conducted in which selection for increased weight of testes at 150 days of age (TS line) was practiced. A randomly selected line (control, C line) was also maintained for 10 generations. The purpose of this article is to report results of an experiment which evaluated differences in quantity and quality of semen produced by boars of the TS and C lines.

Semen was collected from boars 3 times per week or daily when boars were between the ages of 8 and 13 months.

Materials and Methods

The selection experiment and responses in weight of testes and in body weights and backfat depths of boars and gilts after 6 generations of selection were described in the 1990 Nebraska Swine Report. Therefore, only a brief description of the selection experiment will be given here.

The population was a Large White-Landrace composite. In the base generation littermates were randomly assigned to the TS and C lines. Thereafter, lines were closed - all replacements in each line were selected from within the line. Lines were maintained with 40 to 45 litters by 15 sires each generation, and the generation interval was one year.

At 140 and 160 days of age, width and length of paired testes were measured with a calipers and these measurements were used to predict weight of testes at 150 days of age (PWT). In line TS, all males were left intact. The 15 boars with the greatest PWT were selected each generation. At least one gilt was randomly selected from each litter. In line C, one boar was selected randomly from each half-sib family, and at least one gilt was selected randomly from each litter.

There were two replications of the experiment reported herein that were done in two years. In year 1, 6 C and 14 TS boars from the 10th generation were used and in year 2, 12 C and 11 TS boars from the 11th generation were used. These boars were selected randomly from within half sib families. Therefore, each boar had a different sire and dam.

When boars were between 7.5 and 8 months of age, they were transported from the experimental herd at the Agricultural Research and Development Center, Mead, NE, to the Animal Science Building, Lincoln, NE. They were individually penned in a room in which there was a semen collection area (2.5 x 2 meters) with a dummy and an area for processing semen. During the experiment boars were fed 2.5 kg per day of a diet formulated to contain 14% crude protein. Temperature was maintained at approximately 20° C.

Within four weeks of arrival, all boars had been trained to mount the dummy and their semen could be collected. Then they were placed on a schedule of three collections per week for three weeks followed by daily collections for three weeks. At three collections per week semen was collected from each boar on Mondays, Wednesdays and Fridays or on Tuesdays, Thursdays and Saturdays. After the period of daily collections, semen was collected once per week for five weeks from each boar. A five-week rest period was used because the length of the cycle of the seminiferous epithelium, the interval of time for one complete series of cellular associations to appear within the seminiferous tubules, is approximately 39 days in the boar. After the rest period, semen was again collected three times per week followed by daily collections for three weeks.

When semen was collected, the times from when boars entered the collection area to when they mounted the dummy and from when the penis was gripped to when the ejaculation was completed were recorded. Volume of the sperm-rich fraction of the semen was recorded. The sperm-rich fraction is the second part of the ejaculate. It is the viscous-chalky, milky-white portion that contains 80 to 90% of the total spermatozoa. Semen samples were used

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to determine percentage of motile sperm, percentage of abnormal sperm, concentration of sperm cells and total number of sperm cells per ejaculate.

Sperm motility was determined subjectively by observing sperm cells in undiluted semen under a microscope (100 x). After properly staining, morphology of sperm cells was determined by observing 10 sperm cells in each of 10 different microscopic fields. Sperm cells with piriform head, tapering head, narrow head, small head, giant head, short wide head, coiled tail, abnormal attachment of the midpiece, distal plasmic droplet, proximal plasmic droplet, no tails, and double head were classified as abnormal and expressed as a percentage. A spectrophotometer was used to determine concentration of sperm cells and total number of cells was determined by multiplying concentration times volume.

After the last of the 64 semen collections taken from each boar, the boar was castrated and the right epididymis and testis were separated and weighed. Three samples of one gram each from the proximal, mid, and distal regions of the testis were used to determine daily sperm production. The number of mature sperm cells in the cauda region of the epididymis was determined. The tissue was homogenized and the number of homogenization resistant sperm nuclei was counted in duplicate for each sample with a hemacytometer.

Results

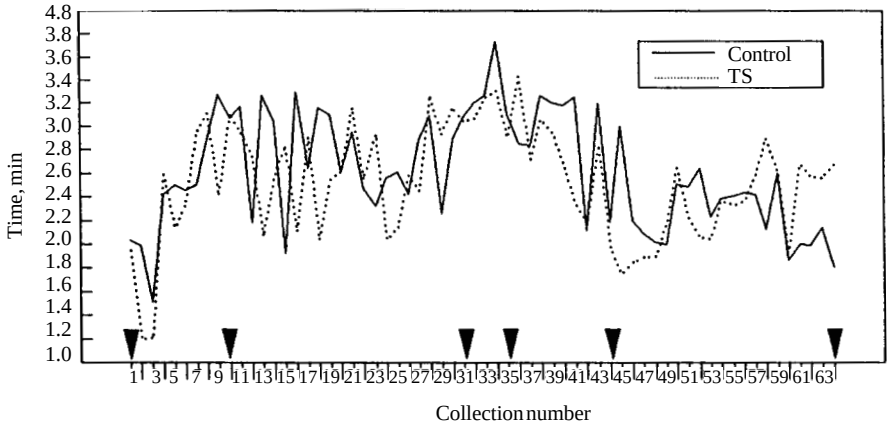
At the 10th generation, PWT for line TS boars averaged 555.7 g compared to 337.4 g for C boars. The average response per generation was 19 g, 5.5% of the base generation mean. The trait directly selected for, PWT, had a large variance - the within line - generation standard deviation (SD) ranged from 59.2 to 95.9 g. Corresponding coefficients of variation (100 x SD/ mean) ranged from 12 to 28%. There was a large amount of phenotypic variation in PWT, consequently selection differentials were large. The realized heritability was .35 $\pm$ .02, therefore the genetic variance in PWT also was large. Even though selection was practiced in only one sex, the response was approximately twice what normally occurs when selection is for most production or reproduction traits.

Because the direct response to selection was so large, the lines are an excellent resource to measure responses in correlated traits. It is generally thought that selection for increased size of testes will increase reproductive characteristics of males. The remainder of this paper describes the effects of this selection on semen characteristics of boars.

Data from three collections per week and daily collections were analyzed separately because variances for several traits were different for these two treatments. Within each treatment, analyses were done to determine if there were line x period (period 1 was collections at the younger age, and period 2 the second sequence of collections at the older age) and line x collection number and line x period x collection number interactions. Line x period interactions were significant for several traits, but line x collection number and line x period x collection number were not significant for any trait. Therefore, results are presented graphically to illustrate responses over time, and means for the lines were compared within each period separately for three collections per week and daily collections.

Time to mount the dummy at each collection and results of comparisons of line means are shown in Figure 1. This time increased linearly during the first three weeks of three collections per week, remained flat during the first three-week period of daily collections through the rest period, and then declined linearly during the second three-week period of three collections per week and again remained flat during the last period of daily collections.

TS boars took .4 minutes less ($P < .05$) to mount the dummy during the first period of daily collections, otherwise lines did not differ. During three collections per week, average time to mount the dummy was 2.4 minutes at the younger age and 3.1 minutes at the older age ($P < .01$). However, during periods of daily collections, the average time was 3 minutes at the younger age

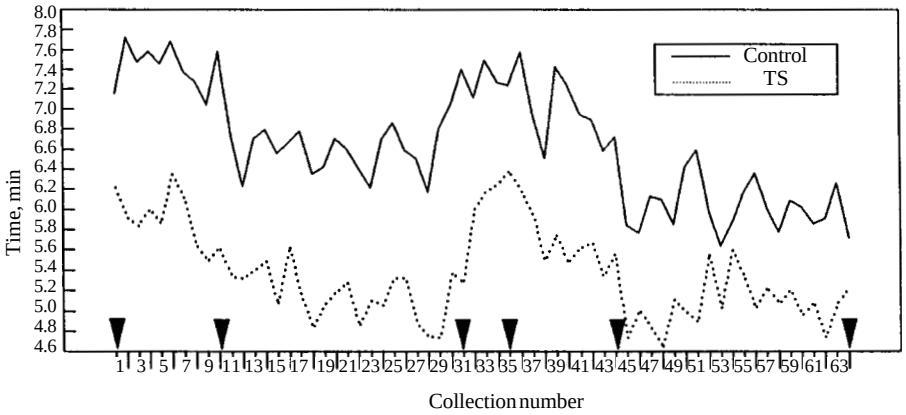


Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	2.5	3.1	3.3	3.2	2.2
TS	2.2	2.7*	3.2	3.0	2.2

**Means differ, P<.01. **Means differ, P<.05.

Figure 1. Time to Mount the Dummy



Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	7.5	6.7	7.3	6.8	5.9
TS	5.9**	5.2**	5.9**	5.7**	5.0**

**Means differ, P<.01. **Means differ, P<.05.

Figure 2. Time to Complete the Ejaculation

and 2.3 minutes at the older age. There is no obvious explanation for this interaction.

Time to complete the ejaculation is illustrated in Figure 2. No interactions were found for this trait. TS boars took from .9 to 1.6 minutes less (P < .01) to complete the ejaculation than C boars. There was a gradual, linear decline over collections until the rest period in both TS and C boars, when average time increased, followed again by a decline until the end of the experiment. At three collections per week, means for younger and older boars were 6.7 and 6.3 minutes (P < .01), respectively.

Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	173.6	145.3	193.1	173.5	141.3
TS	163.4*	138.3**	186.9	170.3	145.6*

**Means differ, P<.01. **Means differ, P<.05.

Figure 3. Volume of Sperm-rich Fraction

During periods of daily collections, younger boars averaged 5.9 minutes and older boars 5.5 minutes (P < .01) to complete the ejaculation.

Volume of semen per ejaculate declined linearly during the first period of three collections per week and reached a lower plateau during the first period of daily collections (Figure 3). Volume quickly increased during the rest period to an amount greater than at the beginning of the experiment. The linear decrease in volume during the second period of three collections per week was similar to that in the first period. During the second period of daily collections volume declined further, but the rate of decline was less. The interaction of line x period was not significant. Volume of semen for TS boars was consistently less than for controls, and line differences were significant during each period except the second period of three collections per week. Within treatment, volume was greater (approximately 3 mL) for older than younger boars, but these differences were not significant.

Percentage of motile sperm decreased linearly during both periods of three collections per week, but the rate of decline was relatively small (Figure 4). During daily collections at the younger age, the rate of decline in motility was quadratic. The decline was sharp for the first 7 days, and then a lower plateau was reached. The response was similar at the older age during daily collections except the early rate of decline was less steep and the lower plateau was at a greater value. Lines responded similarly over time. They also did not differ during periods of three collections per week, but percentage motility was greater (P < .01) for TS boars during periods of daily collections. At three collections per week, percentage motility did not differ between younger and older boars, but at daily collections, motility averaged 73.8% for boars at the younger age and 77.6% (P < .01) at the older age.

Percentage of total abnormal sperm cells increased during the experiment

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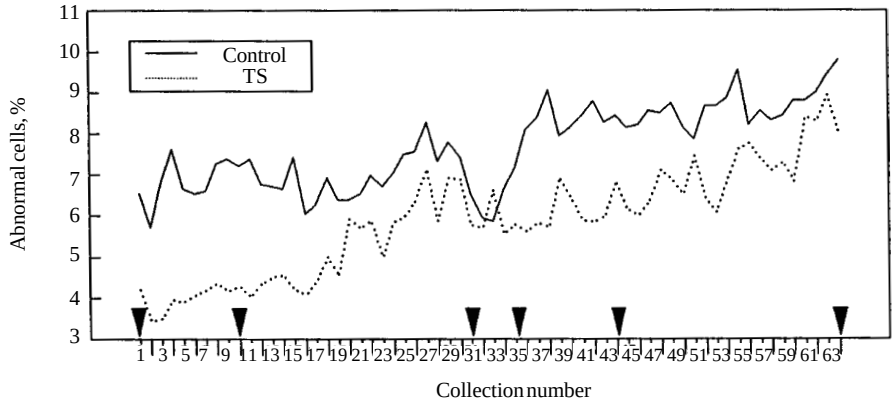
Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	82.0	72.8	84.7	81	76.7
TS	82.7	74.8**	83.4	82	78.9**

**Means differ, P<.01. **Means differ, P<.05.

Figure 4. Percentage of Motile Sperm Cells



Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	6.0	6.7	6.3	7.6	8.3
TS	4.2**	5.2**	5.9	5.9**	7.0**

**Means differ, P<.01. **Means differ, P<.05.

Figure 5. Percentage of Abnormal Sperm Cells

Table 1. Comparison of excised testicular characteristics of control (C) and large testes size line (TS) boars

Characteristics	C	TS
No. of boars	18	23
Average slaughter wt., kg	169.8 ± 3.1	173.8 ± 3.2
Trimmed testes wt., g	286.5 ± 13.7	359.5 ± 11.2**
Epididymal wt., g	60.8 ± 2.5	79.2 ± 2.1**
Tunica wt., g	27.9 ± 2.0	36.2 ± 1.6**
Parenchymal wt., g	255.1 ± 12.3	318.0 ± 10.1**
Total testicular sperm, billion	39.0 ± 2.9	57.7 ± 2.4**
Daily sperm production, billion	8.9 ± 0.7	13.2 ± 0.5**
Total sperm reserves, billion	101.6 ± 6.6	138.9 ± 5.4**

** Means for control and TS differ, P < .01.

(Figure 5). The lines responded similarly over collection number and at each period except the rest period; TS boars had a lower (P < .01) percentage of abnormal sperm cells than C boars. During both treatments, the frequency of abnormalities was greater (P < .01) for boars at the older age (5.1 vs 6.8% at 3 collections per week, and 6.0 vs 7.6% at daily collections).

Concentration of sperm cells (Figure 6) and total number of sperm cells per ejaculate (Figure 7) were greater (P < .01) for TS boars at each period. Concentration declined linearly during both periods of three collections per week, and then declined quadratically during both periods of daily collections. The response in total sperm cells was similar.

Although TS boars had less volume of semen than C boars (Figure 3), because sperm concentration of the semen was greater (281.8 *vs* 246.8 million cells per mL at 3 collections per week, and 156.3 *vs* 126.7 million cells per mL at daily collections), total number of sperm cells per ejaculate was greater for TS boars. The advantage for TS boars was 5.9 billion cells at three collections per week, and 4.3 billion cells at daily collections. Older boars had greater concentrations of sperm cells in the semen and larger numbers of sperm cells per ejaculate (P < .01) than younger boars at both three collections per week and daily collections.

Means for characteristics of excised testes for TS and C boars are in Table 1. Body weights were similar for boars of the two lines, but for all other traits, means were greater (P < .01) for TS boars than C boars. TS boars had larger testes and epididymides than C boars and produced more sperm cells per day and had greater numbers of sperm in the epididymides.

Discussion

At the end of 10 generations the difference in predicted weight of paired testes at 150 d was 218.3 g. In the present experiment, the difference between TS and C boars in weight of the right testis was 73 g at approximately 13 months of age, and the difference in

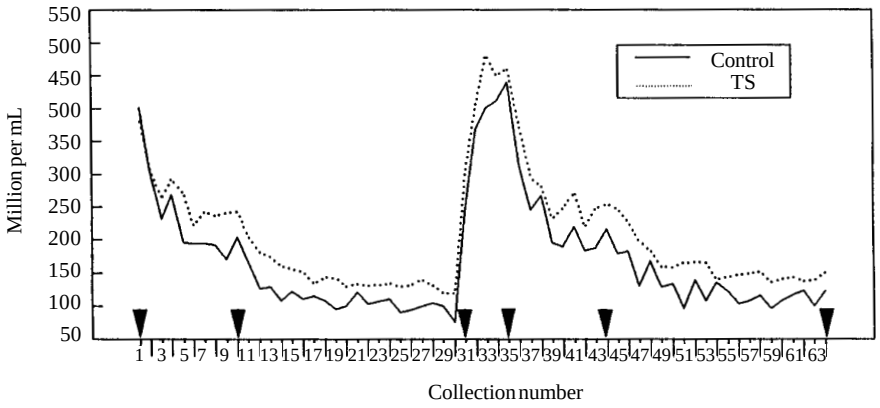
weight of the epididymis was 18.4 g. If these differences are summed and doubled, the difference in weight of paired testes and epididymides was 182.8 g. This result agrees with findings of other experiments that differences in weight of testes between lines was greatest at ages from 130 to 160 d, but that line TS maintains a significant advantage compared to line C to older ages.

The effects of genetic increase in size of testes were that boars produced more sperm cells per day within seminiferous epithelium of the testes and had greater numbers of mature sperm cells in the epididymides. TS boars produced less volume of semen than C boars, perhaps because they took less time to complete the ejaculation. Fluids from accessory sex glands make up a large part of the volume of semen, but the effect of selection for large testes on size and output of these accessory glands was not evaluated.

Because TS boars produced more sperm cells per day and had more sperm cells stored in the epididymis than C boars, concentration of sperm cells in their semen was greater and each ejaculate averaged from 3 to 6 billion more sperm cells. This would provide one to two more doses of semen for artificial insemination from each ejaculate of TS boars than C boars.

Semen for artificial insemination is often diluted to contain 3 to 4 billion sperm cells per dose. The average number of doses per ejaculate when boars were collected three times per week would be 14.4 and 12.7 doses of 3 billion cells for TS and C boars, respectively, at the younger age, and 15.5 and 13.9 doses at the older age. The number of doses would have been 6.6 and 5.4 for TS and C boars at the younger age, and 7.9 and 6 doses, respectively, at the older age when boars were collected daily.

Although percentage motility and frequency of abnormalities are not highly correlated with fertilizing capacity of semen, they are general indicators of quality. Because motility of sperm cells was greater and the frequency of abnormal cells was less for

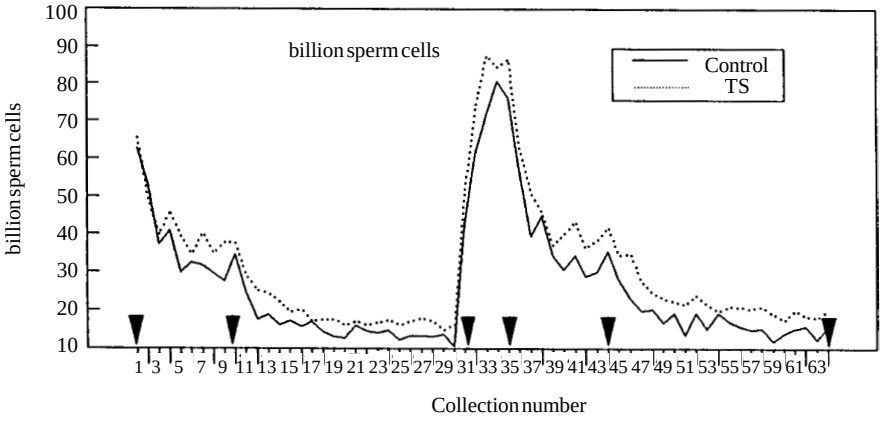


Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	236.1	118.5	355.4	259.0	135.1
TS	274.2**	150.0**	409.7**	297.3**	169.1**

**Means differ, P<.01. **Means differ, P<.05.

Figure 6. Concentration of Sperm Cells



Number 1-9 & 35-43, 3 times/wk; Number 10-30 & 44-64, daily; Number 31-34, 1 time/wk

	P1(3 times/wk)	P1 (Daily)	Rest (1 time/wk)	P2(3 times/wk)	P2 (Daily)
Control	38.1	16.3	64.0	41.8	18.0
TS	43.1**	19.8**	74.2**	49.6**	23.8**

**Means differ, P<.01. **Means differ, P<.05.

Figure 7. Total Sperm Cells per Collection

TS boars, TS boars produced semen with more sperm cells without a loss in general quality of these cells.

Testis size is relatively easy to measure with a calipers. Selection for it could be practiced in seedstock herds. We conclude that this selection would increase the number of sperm cells in each ejaculate of semen. This would be a practical way to increase the efficiency of artificial insemination in swine.

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Index Selection for Components of Litter Size

David Casey
Tom Rathje
Rodger Johnson[1]

Pigs per sow per year has gradually, but steadily, increased in the U.S. during the last 15 to 20 years. More efficient use of better maternal breeds and lines, crossbreeding systems that efficiently utilize heterosis, and improved management and diets are causes for most of this improvement.

Genetic selection to further increase reproductive traits such as litter size and litter weaning rate has recently been implemented and may explain some of the increase in sow productivity in the latter years. However, efficient programs to improve sow reproduction have not been in place long enough to cause much change in the U.S. pig herd.

Continuous application of efficient selection programs in seedstock herds will be necessary to further improve reproductive performance. However, reproductive traits generally have low heritabilities and other traits also must be emphasized in selection programs. Selection accuracy has been increased through the use of computers and genetic analyses to estimate breeding values, but even when these procedures are used, the annual rate of change will not be great. Therefore, there is a need for procedures to speed the rate of improvement from genetic selection for reproductive traits.

Such a procedure was tested experimentally at the University of Nebraska. Selection was for an index of ovulation rate and embryonic/fetal survival rate measured at 50 days of gestation. The experiment was described, and results of the first five generations of selection were reported, in the 1988 Nebraska Swine Report. Selection was continued for another five generations and an additional generation with random selection was produced to evaluate the lines. The purpose of this article is to report the results of this index selection on ovulation rate and on litter sizes at 50 days of gestation and at birth and to briefly discuss the potential application of this selection method.

Materials and Methods

The experiment began in 1981. A composite population of Large White x Landrace cross was used. Littermates in the base generation were randomly assigned to the index line (I) or the control line (C). The selection index was: I_1 = 10.6 x Ovulation Rate + 72.6 Embryonic Survival Rate (generations 0 to 5), and I_2 = 10.6 x Ovulation Rate + 149 x Embryonic Survival Rate (generations 6 to 10).

Size of line I was 40 to 45 litters by 20 sires per generation. Each generation, all female progeny were mated (approximately 160 gilts) to 20 sons of the 15 females with the greatest index value. At 50 days of gestation, laparotomy, a surgical procedure in which the reproductive tract is exposed through the abdomen, was performed. Number of ovulation sites on the ovary and number of fetuses were counted. Embryonic survival was calculated as the ratio of number of fetuses to number of ovulations.

Gilts were ranked for the index and the 45 gilts with the greatest value were selected to farrow. All others were culled before they farrowed. Progeny of the selected females were mated for the next cycle of selection. Therefore, the selection rate was approximately 45 in 160 for dams of gilts, and 15 in 160 for dams of boars.

Line C was maintained with 40 to 45 litters by 15 sires per generation. At least one gilt was selected randomly from each litter and one boar was randomly selected from each half-sib family. Laparotomy was done in approximately half of line C gilts.

Pigs were weaned at 28 days of age, placed in a nursery and fed an 18% protein, corn-soybean meal diet to 56 days of age when they were moved to open front buildings with doors over side openings to regulate temperature and ventilation. They were in groups of 10 pigs per pen, and sexes were in separate buildings.

The diet contained corn or milo, soybean meal, and a vitamin-mineral premix, and was formulated to contain 16% or 14% crude protein. Pigs were switched to the 14% protein diet when the average weight of pigs in a pen was approximately 125 lbs. These diets and those described below contained amounts of vitamins and minerals recommended by NRC.

When gilts reached approximately 200 lbs, they were fed on the floor an amount that averaged 4.5 to 5 lbs of feed daily for each gilt in the pen. This regimen continued until 10 days before breeding began, when the daily feed allotment was increased to 6.5 to 7 lbs

per day to cause the "flushing" effect on ovulation rate. After mating, gilts were placed in gestation stalls and given 4 to 4.5 lbs of feed per day during the last 30 days of gestation. The diet was formulated to contain 11.5% protein. Within three days after parturition, gilts were allowed *ad libitum* access to feed through the lactation period. The diet contained 13.2% protein and 4% tallow.

To better characterize responses to selection, generation 11 was produced with random mating, population size was increased, and randomly selected generation 11 gilts were mated and farrowed without imposing the laparotomy procedure. In the last generations of the experiment, there was an increase in the incidence of mummified pigs and stillborn pigs at birth in index line gilts compared to controls. These losses could have been due to the laparotomy procedure, which could have been more traumatic to the larger litters carried by index gilts, or these losses could be a natural phenomenon in index gilts with increased ovulation rate and litter size.

A nutrition experiment was imposed on generation 11 gilts to determine if the losses described above in the index line gilts could be reduced by increasing nutrients in the diet during the gilt development period beginning at 200 days of age through gestation. The diets compared had either 14% protein plus NRC amounts of vitamins and minerals, or 18% protein plus 50% more vitamins and minerals than those recommended by NRC.

Two lactation diets also were imposed, one had 15% protein plus NRC recommended amounts of vitamins and minerals, the other had 18% protein and 50% more vitamins and minerals than amounts recommended by NRC. All diets contained corn, soybean meal, beet pulp and premix. Lactation diets contained 4% tallow.

A total of 285 generation 11 gilts, 164 index line and 121 control line, were selected for this experiment when they were 56 days of age. Other than the change in diets and elimination of the laparotomy procedure, other management, including amounts of feed fed, were as described above for the selection experiment.

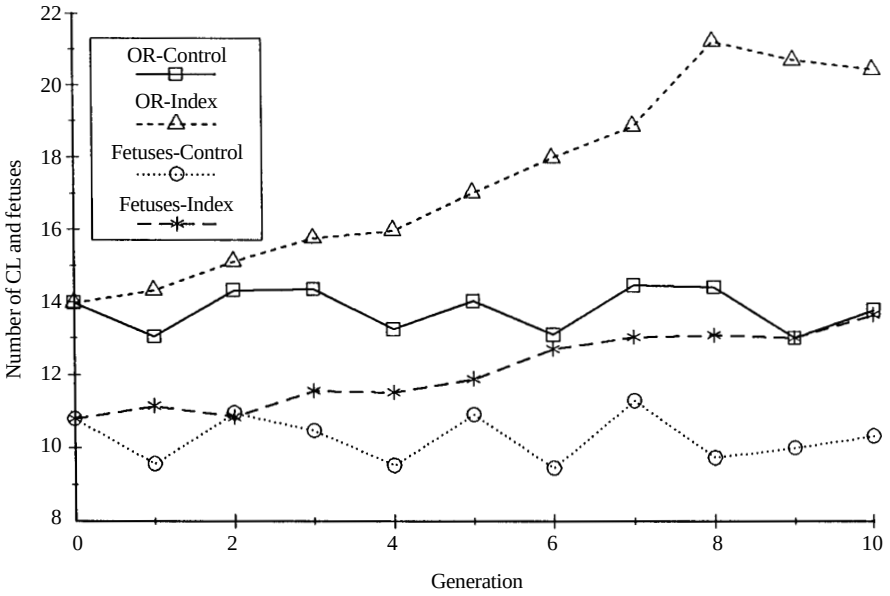

Figure 1. Number of corpora lutea (OR) and number of fetuses at 50 days of gestation

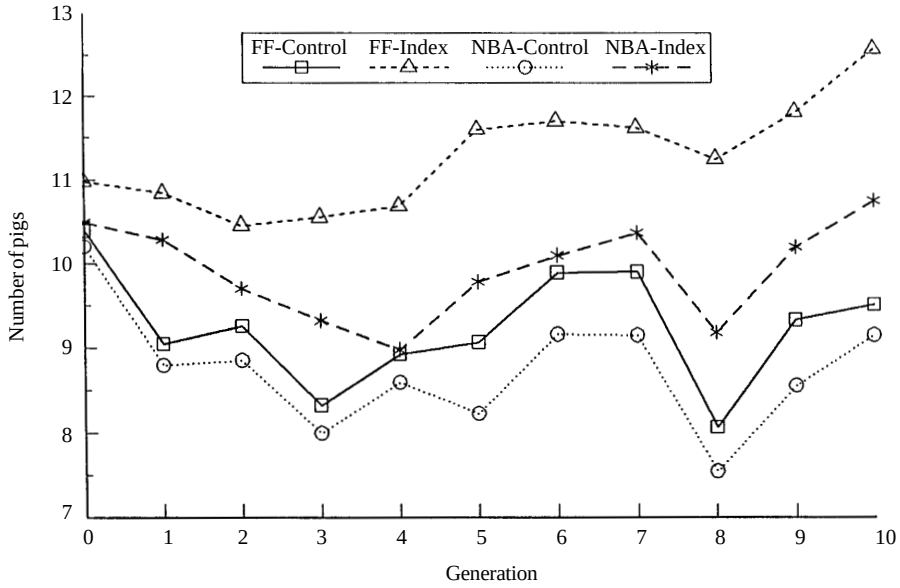

Figure 2. Number of fully formed pigs (FF) and number of pigs born alive (NBA)

Results

Selection Experiment. Line means for ovulation rate and number of fetuses at 50 days of gestation are illustrated in Figure 1. Over all generations, the response per generation (measured as the increase over generations in the difference between lines I and C) averaged .78 $\pm$ .04 ova and .32 $\pm$ .02 fetuses. Therefore, the total response after 10 generations was estimated to be an increase of 7.8 ova and 3.2 fetuses at 50 days of gestation. Embryonic survival actually declined at the rate of -.9$\pm$ .1% per generation.

Figure 2 illustrates the response in number of fully formed pigs and number of pigs born alive. The average

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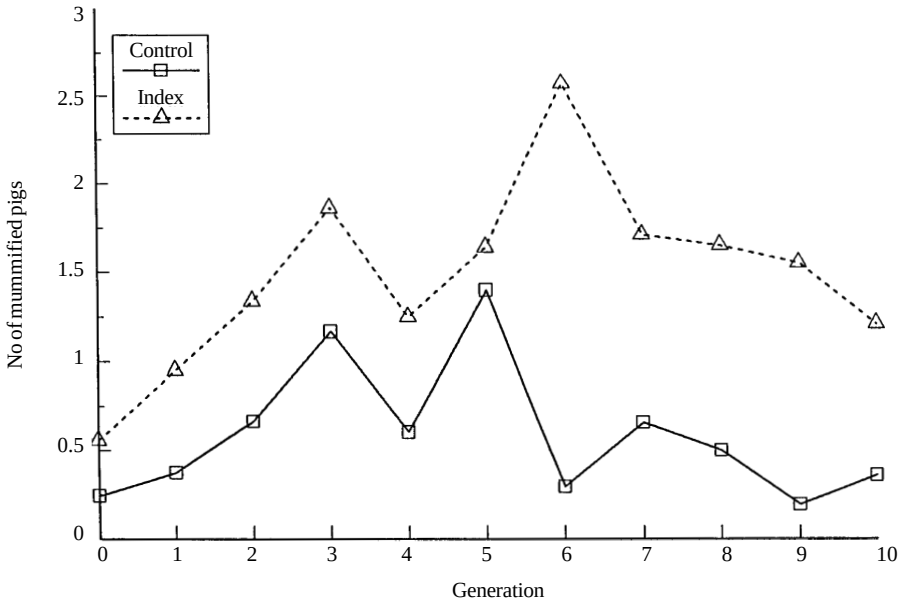

Figure 3. Number of mummified pigs at birth

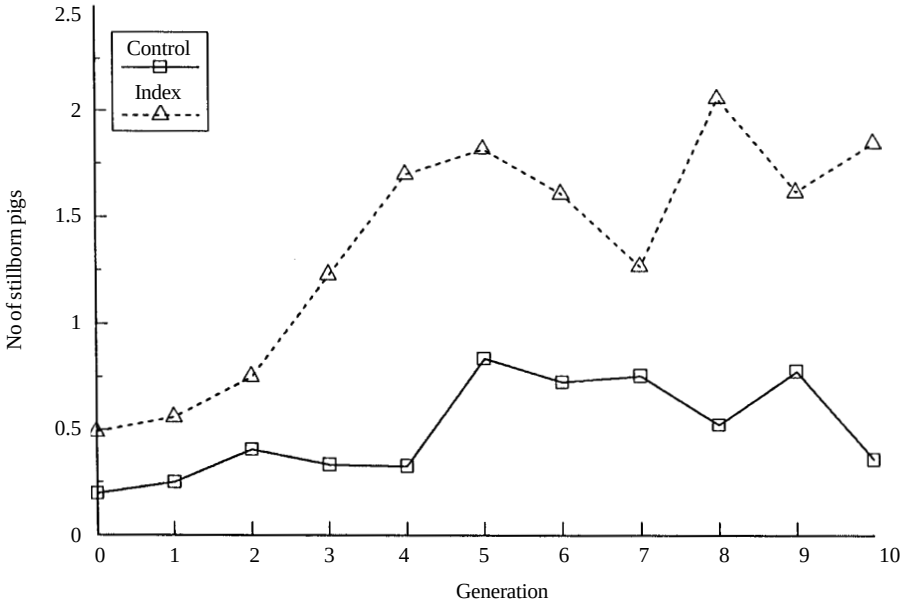

Figure 4. Number of stillborn pigs at birth

response in number of fully formed pigs was .11 ± .05 pigs at birth per generation and the average in number of pigs born alive was only .002 ± .049 pigs per generation.

Index line gilts had significantly more mummified pigs at birth than controls (Figure 3), and the difference increased with generation number. The difference was approximately one more mummified pig per litter for Index line gilts in the latter generations. This explains approximately half of the decrease in response in number of fully formed pigs at birth compared to the response in number of fetuses at 50 days of gestation. The remainder of the loss was due to fetuses that died after 50 days of gestation and were reabsorbed so they were not found as a mummy. The incidence of this loss also increased during the experiment.

The number of stillborn pigs at birth increased significantly with generation number (Figure 4). The increase in number of fully formed pigs was offset by the increase in stillborn pigs so that little change in number born alive occurred.

Generation 11. Of the 164 Index gilts that were selected at 56 days of age, 130 were mated and 119 farrowed a litter, and 111 of 121 Control gilts were mated and 97 of these farrowed a litter. The percentage of gilts that mated and that farrowed was not significantly affected by either genetic line or gilt development diet.

There were no line x diet interactions on any litter traits measured at birth or weaning, nor were diet effects important ($P > .20$) but line differences were significant. Therefore, results in Table 1 are means for the lines, averaged across diets.

Index gilts had litters with 2.2 more ($P < .01$) fully formed pigs at birth than Control gilts, and 1.2 more ($P < .01$) pigs born alive. Because there were more pigs per litter, Index line gilts had heavier (2.9 lbs, $P < .05$) litters at birth, even though average weight of the pigs was less. Gilts of the two lines did not differ in weight of litter weaned after adjustment for numbers nursed by the gilt.

Discussion. The index was designed to place optimum weight on the component traits of litter size, ovulation rate and embryonic survival, so maximum response in litter size could be achieved. Expected rate of response was further enhanced by the method of measuring the traits during gestation. This permitted all gilts to be measured each generation so the selection rate for dams of boars was 15 in 160 compared to 15 in 45 that could have been achieved from direct selection for litter size at birth. So the net effect of the selection method used was more rapid expected response in litter size due jointly to greater selection differentials and opti-

Table 1. Mean litter sizes and weights for Index and Control gilts in Generation 11[a]

	Farrowing			Weaning		
Line	*n*	NFF	NBA	LBW, lb	*n*	LWW, lb[b]
Index	119	11.7**	10.1**	27.6*	116	113.0
Control	97	9.5	8.9**	24.7	95	114.9

* Lines differ, P < .05.
** Lines differ, P < .01.
[a] NFF = number of fully formed pigs at birth, NBA = number born alive, LBW = litter birth weight, and LWW = litter weaning weight
[b] Adjusted for number nursed.

mum weighting on the component traits in the index.

The response in litter size at 50 days of gestation was approximately twice what could be expected from direct selection for litter size at birth in an experiment of similar size. Therefore, the index method was very effective in changing this trait. The expectation from calculations made before the experiment began was that selection for the index would cause a rapid increase in ovulation and that there would be some decrease in embryonic survival rate, but that the net effect would be a substantial increase in litter size. The observed responses at 50 days of gestation agreed very well with these expectations.

When the experiment was started, it generally was believed that most of the embryonic loss occurred during the first 30 days of gestation and that the relationship between litter size at 50 days of gestation and litter size at term would be very high. However, there was substantial fetal death after 50 d of gestation in Index line gilts. Some of this death loss was due to the laparotomy procedure because Control gilts that had the laparotomy consistently had fewer fully formed pigs at birth (average approximately .7 pigs less) and more mummified pigs at birth (average approximately .3)

Therefore, the surgical procedure itself was causing some of the loss after 50 days of gestation. Because in later generations litter size at 50 days of gestation in the Index line was substantially greater than in the Control, it is possible that laparotomy caused more losses in Index line gilts than in Control gilts. However, it is also possible that fetal losses after 50 days of gestation were substantially greater in gilts with large litters because uterine capacity after 50 days of gestation was the limiting component in litter size at birth. If this is the case, the increase in litter size at 50 days of gestation would be partially offset by fetal losses, many of which would be found as mummified piglets at birth. Partitioning these variables as causes of fetal losses after 50 days of gestation required measurements of litter size without laparotomy in random samples of gilts from each line, which was done in generation 11.

The increase in number of stillbirths in litters by Index line gilts is difficult to explain. These pigs were fully formed and normal in size and likely died during parturition. We do not know whether stillborn pigs were normally born after a mummified piglet was expelled. However, Dr. Phil Dzuik, University of Illinois (personal communication) has observed that a pig born after a mummified pig is often stillborn. The reason, he speculated, was that the uterus is constricted at the location of a mummified pig and the length of time for the birthing process is delayed for the next live pig passing through this area, and this delay could cause its death.

The generation 11 experiment confirmed that litter size increased from the index selection. When no laparotomy was performed and a random sample of gilts was used, the difference in number of fully formed pigs was 2.2 pigs, compared to an estimated difference of 1.1 pigs at generation 10. Further, when no laparotomy was done, lines differed by 1.2 pigs born alive. Therefore, we conclude that this index selection did increase litter size at birth, that the laparotomy procedure was more traumatic to Index gilts with large litters than Control gilts, and that fetal losses after 50 days of gestation are greater in Index line gilts than Controls. The last point follows from the fact that lines differed by 3.2 fetuses at 50 days of gestation, of which 2.2 was observed as a fully formed pig and 1.2 as a live pig in the generation 11 sample. Because diet did not affect the reproductive traits and there was not a diet x line interaction, we conclude the increased reproductive potential of the Index line gilts cannot be realized by feeding diets with more protein, vitamins and minerals than those recommended by NRC.

We conclude that the index selection method used in this experiment can be used to enhance rate of response above that expected from normal litter size selection. However, to enhance response in litter size at birth the index should be based on ovulation rate and litter size at term. It is not recommended that selection at 50 days of gestation, as used in this experiment, be applied by the industry. Rather, procedures should be developed to jointly select for ovulation rate and uterine capacity to term to effectively utilize these methods.

[1]David Casey and Tom Rathje are graduate students, and Rodger Johnson is a Professor in the Department of Animal Science at the University of Nebraska, Lincoln.

Legal Aspects of Swine Production Networking

J. David Aiken[1]

Some Nebraska swine producers may wish to consider entering into joint production operations with other producers. This might be to physically separate the farrowing, nursery and feeding operations. Some industry observers believe that networking may allow smaller producers to collectively achieve economies of scale and other production advantages often available only to larger producers.

Producers considering entering into joint livestock production arrangements should consult an attorney. Liability and income tax considerations, and Initiative 300 must all be considered in legally structuring joint livestock production operations to meet the special needs of each group of producers. This article provides a brief overview of some legal issues involved in structuring joint livestock operations, particularly the role of a family farm limited liability company in networking. This information does not constitute legal advice but is provided for educational purposes only.

Liability concerns. If neighbors enter into joint livestock production, each of them risks making all their farm (and perhaps personal) assets available to the joint operation's creditors. For example, unrelated neighbors Smith and Jones decide on a handshake basis to establish a joint livestock enterprise. Smith contributes 10 acres, a confinement facility and labor to the enterprise, while Jones contributes 100 sows, feed and labor. Both Smith and Jones have cropland outside of and legally separate from their joint livestock operation.

Legally Smith and Jones are considered to have established a partnership, even though they have no formal written partnership agreement. As partners, all the assets owned by Smith and Jones in their own name (or jointly with their spouses or other family members) are legally available to satisfy any financial or legal obligation of the Smith-Jones livestock partnership. Suppose Smith and Jones borrow money from Local Bank to purchase more sows. If there is not sufficient cash or other assets in the Smith-Jones livestock operation to pay the loan when due, Local Bank could foreclose on either Smith or Jones' cropland to pay the livestock loan, even though the cropland is not part of the Smith-Jones livestock operation.

Limited liability. Normally participants in joint business operations, like the Smith-Jones livestock partnership, seek to limit the assets (cash, land, livestock or other property) at risk in the business to the assets they have actually contributed to the business. This is to avoid having property from outside the business being foreclosed upon to satisfy a business debt, as happened to Smith and Jones above.

Legally limiting this liability risk can be accomplished by operating the business in a legal entity which gives limited liability to all business participants. In Nebraska all business participants can obtain limited liability either in a corporation or in a limited liability company (LLC).

Initiative 300 (I300) restricts corporations that are legally authorized to engage in agricultural operations (including livestock production) to family farm corporations. To qualify as a family farm corporation (FFC), all of the following requirements must be met:

1. a majority of the FFC's stock must be owned by family members;
2. a family member must either:
   i. live on the farm or ranch, or
   ii. provide daily labor and management; and
3. no non-family farm corporations or limited partnerships may be FFC stockholders.

LLCs are a new form of business entity in Nebraska and are a cross between a partnership and a corporation. Statutes authorizing the establishment of LLCs were adopted in 1993. LLCs combine the operational flexibility and informality of a partnership with the limited liability protection of a corporation. LLC statutes restrict the LLCs that are legally authorized to engage in agricultural operations (including livestock production) to family farm LLCs. In family farm LLCs:

1. all LLC members must be family members and
2. one family member must either:
   i. reside on the farm or ranch, or
   ii. provide daily labor and management.

Family farm corporation networking. FFCs may provide a way for neighbors to network livestock operations, as long as family members own a majority of corporate stock and a family member lives on the farm or provides daily labor and management. Thus Smith and Jones could incorporate and meet FFC requirements if either Smith or Jones met all the FFC requirements for the Smith Jones corporation. For example, Smith (or Jones) could own 51% of the stock and live on or work and manage the farm. If three neighbors were involved, one of the three would have to meet the FFC requirements of owning at least 51% of the stock and living on or working and managing the farm. The corporate stock could not be divided 50-50 between two neighbors or 1/3-1/3-1/3 between three neighbors (unless the neighbors were also related).

The decision to establish a corporation has important legal and tax implications. While some employee benefits may be deductible in a corporation, capital gains tax may be due on appreciated assets (such as land) contributed to the corporation if the corporation is dissolved. In addition, considerable formality is required for corporation operations, including family farm corporations. Shareholder and board of director meetings must be held, records of all meetings must be maintained, and the business must be run through the corporate officers. If these corpo-

rate formalities are ignored, both limited liability and corporate tax deductions may be lost. The decision to incorporate is important and can be made only after carefully considering of all advantages and disadvantages.

Limited liability company networking. Another possibility is networking through family farm LLCs. Smith could form an individual LLC consisting of his 10 acres and building, while Jones could form his own LLC consisting of his sows. Then the two LLCs could form a partnership. However because both LLCs would have limited liability, Smith and Jones' liability exposure would be limited to the property in their respective LLCs. Note that in this case both Smith and Jones would have to provide daily labor and management for each of their LLCs to qualify as a family farm LLC.

LLCs do have some operational advantages over corporations. The corporate formalities of shareholder meetings, election of officers and directors, and maintaining records of shareholder, officer and director meetings are not required. Capital gains on appreciated property generally are not imposed if the LLC is dissolved. However, certain employee benefits that may be fully deductible only in a corporation are not fully deductible within an LLC.

In addition to networking through FFCs or family farm LLCs, combination of FFCs and family farm LLCs could network through a livestock production partnership, with each partner having limited liability as a FFC or family farm LLC. Even though partners generally have unlimited personal liability for partnership debts and legal obligations, if the partner is a limited liability entity (like a FFC or family farm LLC) then that partner's partnership liability is limited to the assets of the FFC or family farm LLC.

If you have questions about networking and how to legally structure a networked livestock operation, contact an attorney.

Feedlot Nuisance and the Nebraska Right to Farm Act

J. David Aiken[1]

Livestock operations located near private dwellings (including farmsteads) are often the subject of nuisance lawsuits because of the odor and flies generated. For many years the Nebraska Supreme Court ruled that a feedlot was legally not a nuisance as long as it was properly maintained, regardless of the feedlot's effect on neighbors. Beginning in 1975, however, the Court changed its position, ruling that feedlots could legally constitute a nuisance even if they were maintained with due care. If the feedlot is a nuisance, the operator could be required by the court:

1. to pay money damages to the neighbor,
2. to control the nuisance, or
3. to discontinue the feedlot.

In 1982 the Nebraska Right to Farm Act was adopted, which protects feedlots from nuisance lawsuits if the feedlot was there first. The Right to Farm Act, however, does not protect feedlots when they expand and a neighbor objects.

No negligence, no nuisance. For many years the Nebraska Supreme Court ruled that feedlots were not nuisances as long as they were properly maintained. In a typical 1943 decision, the Court concluded that the feedlot operator used reasonable techniques to minimize feedlot odors, and ruled that a feedlot was a nuisance only when improperly maintained or conducted, regardless of its effect on neighbors.

Feedlot a rural nuisance. This legal philosophy changed in 1976. A Colfax county farmer sued his neighbor for maintaining a large livestock operation as a nuisance. The livestock operation was across the road from neighbor's farm house. Between 408 to 3,746 cattle were fed. The trial judge found that the neighbors were subject to "intolerable" dust, odors, and flies from the feeder's four livestock waste lagoons, and that the neighbors' property value had been reduced. However, the trial judge dismissed the case, following the "no negligence, no nuisance" rule. The trial judge determined that a feedlot could not legally constitute a nuisance in the country in Nebraska unless the feedlot was improperly operated.

On appeal the Nebraska Supreme Court reversed the trial judge and ruled that the case could go to trial. The court ruled for the first time in Nebraska that due care in the operation of a feedlot was not a defense to a nuisance suit. The fact that the feedlot was located in a rural area was one factor to consider, but was not enough alone to prevent the feedlot from legally constituting a nuisance. The court stated that a feedlot cannot be maintained in a manner to injure a neighbor even in a rural area. In short, the mere showing by the feedlot operator that he used reasonable techniques to minimize feedlot odors etc. was no longer enough to win the case for the feedlot.

Feedlot operation improved. In the second phase of the Colfax county cattle feedlot case, the Nebraska Supreme Court ruled in 1980 that the feedlot legally constituted a nuisance due to the flies and odors generated. The court gave the feedlot operator two choices,

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to control the nuisance or discontinue operations.

In response to the court order, the feedlot operator relocated three of the original four feedlot waste lagoons away from the neighbor's farmhouse, a portion of feedlot was relocated, and the former lagoons and feedlot area were filled and converted to pasture. The manure was bladed up, combined with dirt, and mounded spring and fall. Many witnesses testified that they no longer noticed the feedlot odor from the road.

The trial judge ruled that the nuisance had been stopped. The Nebraska Supreme Court affirmed in 1981. The Court stated that the defendants were not required to operate their feedlot with zero flies, odors or dust, but were required to control the nuisance so as not to interfere with the neighbor's residence.

Feedlot ordered to close. In a 1981 feedlot case from Franklin county, the feedlot operator was under court order to control the nuisance or discontinue the feedlot. The neighbor's farmstead predated the feedlot. Even though feedlot management improved, the feedlot itself was so large and so close to the neighbor's farmstead that the feedlot still constituted a nuisance, regardless of method of operation. The feedlot operator's own expert witness conceded that it would be impossible to operate this feedlot (800 sows and 6,000-7,000 hogs) without creating an odor problem for farm residences located within a half mile of the feedlot. The plaintiff's home was 1,030-1,400 feet from the defendant's closest holding pond, less than one-quarter mile.

The Nebraska Supreme Court in 1985 affirmed the order of the trial court closing the feedlot. The court noted once again that due care (i.e. lack of negligence) in operating a business is not in and of itself a defense to nuisance. The defendants had 20 months to control the nuisance and were unable to do so. The court stated "it is inconceivable that so many hogs could be kept in the defendants' [hog] facility in such close proximity to the plaintiff's [farmstead] and not be offensive."

Feedlot nuisance damages. In two feedlot cases the feedlot was required to pay damages for flies and odors from the feedlot. In a 1980 case from Merrick county, a cattle feedlot owner was required to pay his neighbor $50,000 for building a feedlot across the road from the neighbor's farmhouse. In a 1994 case from Holt county, the Nebraska Supreme Court affirmed a $376,000 jury award against National Farms for flies and odors from its feedlot. The feedlot had 85,000-90,000 hogs and generated considerable flies and odors. The neighbors suing National Farms lived 2-1/4 mile northeast of the feedlot. These decisions indicate that livestock feeders may be subject to substantial financial penalties if they locate too close to a neighbor.

Right To Farm Act. In 1982 the Nebraska Right to Farm Act was adopted. The act provides that a farming operation [of at least 10 acres] is not a nuisance if it would not have constituted a nuisance before the neighboring land uses or occupancy changed. "A farm or a farming operation is not a public nuisance if the farm or farming operation existed before a change in the land use or occupancy of land in and about the locality of such farm or farm operation and before such change in land use or occupancy of land the farm or farm operation would not have been a nuisance." NRS §2-4403.

The Right to Farm Act protects existing feedlots if a neighbor "comes to the nuisance," i.e. moves next door to an existing feedlot. However, Right to Farm does not protect new or expanded feedlots. If a feeder expands his lot, existing neighbors may challenge the expanded feedlot as a nuisance even if the neighbor could not have objected to the original feedlot under Right to Farm.

The Right to Farm Act has been interpreted only once by the Nebraska Supreme Court, in a 1985 feedlot case from Gage county. The farmer began farming in 1961, and sold an acreage in 1968. In 1981 the farmer established a 400-head confined hog facility within 133 feet of the neighbor's house on the acreage. The neighbor sued, arguing that the confinement facility constituted a nuisance. The neighbor was awarded $2,000 in damages and the feedlot was ordered to be shut down.

On appeal to the Nebraska Supreme Court, the feeder argued that he was protected by Right to Farm because he had been farming since 1961 and the acreage was not established until 1968. However the Nebraska Supreme Court ruled that because the hog operation was not started until 1981, the 1968 acreage was protected under Right to Farm not the 1981 feedlot.

Feedlot location. Feedlot operators should take into account the location of neighbor's residences when making a decision to locate a feedlot. If possible, the feedlot should not be visible from the road. The feedlot operator should also use best available management techniques to minimize odors, flies, and other feedlot nuisance factors. The same factors should be considered where an existing feedlot is significantly expanded.

In Nebraska, the courts have consistently ruled that a new or expanded feedlot operation must be located so as to not constitute a nuisance for existing neighbors. This legal rule is not modified by the Right to Farm Act. Where the feedlot has the earliest occupancy date (i.e. is first in time) it generally will not constitute a nuisance to those who have "come to the nuisance."

Where a new feedlot is installed, however, or an existing feedlot is expanded, the feedlot operator faces the likelihood of having to relocate if the new or expanded feedlot causes a nuisance to any current neighbors. In light of this, feedlot operators must make locational decisions very carefully--if they ignore the potential nuisance effect of their operation on their neighbors, they risk having to either discontinue the feedlot or else pay significant money damages. Feedlot operators ignore this blunt legal fact at their peril.

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Estimation of Pork Trim Composition by Electromagnetic Scanning

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The value of pork trim depends on its lean content. Accurate assessment of composition is necessary for proper pricing. Procedures often used to estimate composition lack accuracy and require time, thus a rapid, accurate, non-invasive technology to determine lean content of pork trim is needed.

Electromagnetic scanning, also known as ToBEC (total body electrical conductivity), has been studied for prediction of lean in hams (see 1994 Swine Report, p. 8). The equipment consists of a stainless steel cabinet containing a large, plastic-covered coil, through which meat is conveyed. Energy is absorbed from the electromagnetic field by the sample. Because lean is more conductive than fat, the peak of the scanning curve is highly related to lean content. Prior research has demonstrated a strong relationship between electromagnetic scanning and pork carcass lean content (see 1994 Swine Report, p. 5). This study was conducted to evaluate electromagnetic scanning for estimation of pork trim composition.

Materials and Methods

Right sides from 74 carcasses were chilled and boned. Boneless pork trim from each side was allocated to plastic tubs and standardized to 70 lb (n = 51) or 40 lb (n = 23). Animal variation prevented uniform weights of trim. Temperature of trim was recorded and tubs were scanned in duplicate using an electromagnetic scanner at 2.5 MHz. Pork trim was ground to 2.5 cm in particle size and rescanned in duplicate. Oven drying and ether extraction were used to determine moisture and fat content.

Equations for prediction of fat-free lean weight and percentage were generated using peak of the scanning curve, meat temperature and trim weight. All possible one-, two-, and three-variable equations were created, but results are presented only for those which had the highest R^2 with the lowest root mean square error.

Results and Discussion

Although an attempt was made to standardize trim weight, a small variation existed (Table 1). This occurred because some sides yielded less lean trim than the target weight. The pork trim was quite variable in composition, slightly more so for those allocated to a target weight of 70 pounds (Table 1). Differences in tub weight resulted in much lower peaks of the scanning curves for the 40-pound tubs ($\bar{x}$ = 35) than the 70-pound samples ($\bar{x}$ = 108).

Because peak of the scan curve is influenced by sample size and temperature, these variables were included in the analysis. Alone, neither sample size or temperature accounted for much of the variation in composition (Table 2). There was a strong association between peak of the scan curve and fat-free lean content (Table 2). The magnitude of this correlation was greater for the 70-pound sample than the 40-pound sample. The manufacturer specifies a minimum sample size of 30-pounds for this scanning unit. It appears that sample sizes larger than 40 pounds are needed for maximum accuracy.

Nearly twice as much of the variation in fat-free lean content was explained in the 70-pound sample than in the 40-pound sample (Table 3). It was also apparent that grinding produces a more homogenous sample, which improved predictive accuracy in the heavier tubs. Meat temperature (for weight of fat-free lean) in conjunction with meat weight (for percentage fat-free lean) added small but significant improvements in prediction of

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Table 1. Characteristics of pork trim.

Tub weight, lb.	Trait	n	Mean	Standard deviation	Minimum	Maximum
70	Trim weight, lb.	51	69.9	0.42	67.8	70.0
	Lean trim temperature, F	51	43.2	2.49	39.0	50.0
	Ground lean temperature, F	51	43.9	2.52	41.0	52.0
	Fat-free lean weight, lb.	51	43.6	3.73	35.3	52.8
	Fat-free lean, %	51	62.4	5.38	50.5	75.5
40	Trim weight, lb.	23	40.0	0.10	39.5	40.0
	Lean trim temperature, F	23	41.8	4.16	36.9	49.0
	Ground lean temperature, F	23	44.0	3.75	39.6	51.0
	Fat-free lean weight, lb.	23	26.8	1.69	23.1	30.6
	Fat-free lean, %	23	67.0	4.25	57.6	76.4

Table 2. Correlation coefficients for pork trim and scanning characteristics to fat-free lean.

		Fat-free lean weight			Fat-free lean, %		
Tub weight, lb.	Particle Size	Meat temp.	Meat weight	Scan peak	Meat temp.	Meat weight	Scan peak
70	Lean trim	.05	.08	.83	.04	.15	.82
	Ground lean	.10	.03	.90	.11	.12	.89
40	Lean trim	.14	.20	.67	.12	.24	.67
	Ground lean	.12	.20	.60	.11	.24	.60

composition (Table 3) for the 70-pound samples. Conversely, neither grinding nor temperature nor weight improved prediction for the 40-pound samples.

Electromagnetic scanning is effective and accurate (within 2 pounds or < 3%) for prediction of fat-free lean in pork trim, presuming sample size is sufficient.

Table 3. Prediction of fat-free lean in pork trim.

Tub weight, lb.	Particle size	Fat-free lean weight			Fat-free lean, %		
		Model	R^2	RMSE, lb.[a]	Model	R^2	RMSE,%
70	Lean trim	Peak, temp.	.714	2.04	Peak, temp., wt.	.723	2.92
	Ground lean	Peak, temp.	.821	1.62	Peak, temp., wt.	.829	2.29
40	Lean trim	Peak	.451	1.28	Peak	.455	3.22
	Ground lean	Peak	.358	1.38	Peak	.362	3.48

[a]RMSE = root mean square error.

[1]N. L. Meseck and B. L. Gwartney were graduate students, and C. R. Calkins is a Professor in the Animal Science Department at the University of Nebraska - Lincoln.

Effect of Cooking Method on Nutrient Content of Boneless Pork Loin Roasts

Judy A. Driskell
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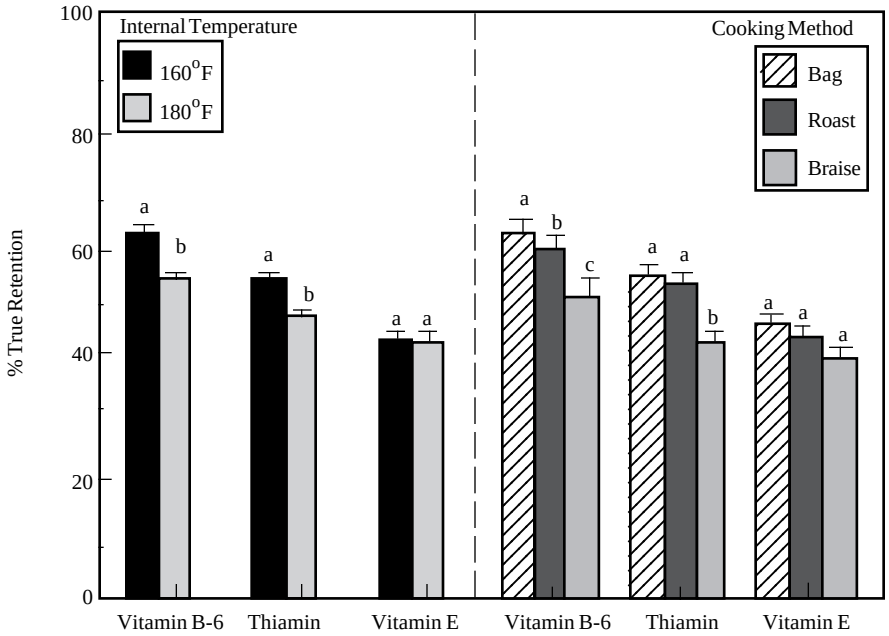
The nutritive qualities of boneless Chef's Prime™ pork loin roasts cooked by three household cooking methods to two internal temperatures were evaluated. Fresh pork loins were obtained from a vendor and prepared by UNL's Meat Laboratory according to National Pork Producers Council's specifications for the Chef's Prime™ trademarked cut with 1/8-inch fat trim. The roasts were frozen for less than two months before defrosting in the refrigerator and cooking.

The National Pork Producers Council now recommends that pork be cooked to an endpoint internal temperature of 160° F rather than the previously recommended temperature of 180° F. This is because new swine production practices have reduced concerns about trichinosis. Roasts were cooked in a household oven at 325° F to internal temperatures of 160° F (the new recommendation) and 180° F (the former recommendation). The loins were cooked by roasting, braising, and cooking in a large (Reynolds) oven bag. The loin roasts were between 2.4 and 4 pounds. The average cooking times for the roasts are given in Table 1. Pork that was braised or cooked in a bag reached 160° F or 180° F internal temperature much more quickly than pork that was roasted. The cooked pork contained a mean of 68% moisture and 8% crude fat.

Table 1. Average Cooking Time

Cooking method	Internal temperature	
	160°F	180°F
	(minutes)	
Roast	131	164
Braise	107	121
Bag	109	122

Pork cuts are "good" to "major" sources of many nutrients that Americans frequently consume in less than adequate quantities. These include



Values represent least squares means and standard errors.
Values for each nutrient not sharing a common superscript are significantly different at P < .01.

Figure 1. True Retention Values for Three Vitamins in Pork Roasts Prepared by Three Cooking Methods to Two Internal Temperatures

vitamin B-6, vitamin E, iron, magnesium, zinc, and selenium. The amounts of these nutrients in the cooked pork roasts and their retention values were determined. Thiamin was used as the index nutrient. Cooked pork roasts (3.5 ounces) were found to contain approximately 20% of the vitamin B-6, 49% of the thiamin, 2% of the vitamin E, 10% of the iron, 6% of the magnesium, 20% of the zinc, and 89% of the selenium needed to meet the Recommended Dietary Allowances of adults for a day.

True retention is a term that relates the percentage of nutrient content of the food as cooked to the content before cooking. The true retention of the vitamins in the pork roasts prepared by the three cooking methods to the two internal temperatures are given in Figure 1. Retention values for vitamin B-6 and thiamin were significantly higher ($P < .01$) in pork cooked to 160° F than to 180° F. Vitamin B-6 retention values for pork cooked in a bag were significantly higher ($P < .01$) than for pork that was roasted, whereas pork that was roasted had significantly higher ($P < .01$) values than pork that was braised. Thiamin retention values were significantly higher ($P < .01$) in pork that was cooked in a bag or roasted than in pork that was braised. Mean true retention values were 58% for vitamin B-6 and 51% for thiamin. Hence, almost half of the vitamin B-6 and thiamin were destroyed during cooking. The highest true retention values for these two vitamins were for pork cooked in a bag.

The vitamin E retention in pork prepared by the different cooking: temperature methods was similar. The pork roasts contained a small amount of vitamin E, only enough to meet about 2% of recommended intakes per serving. However, the mean true retention value for vitamin E was only 44%, indicating that over half of the vitamin E was destroyed during cooking. This was independent of the cooking: temperature method used. The lower fat trim of today's pork cuts may result in the lower vitamin E content.

True retention values for iron, magnesium, zinc, and selenium were similar for the different cooking: temperature methods and were close to 100%. Hence, no loss of minerals occurred while the pork was being cooked.

True retention values for vitamin B-6, thiamin, and vitamin E were highest for pork roasts cooked in the bag to an internal temperature of 160° F. However, true retention values for iron, magnesium, zinc, and selenium were similar in pork cooked in the bag, braised, or roasted to either 160° or 180° F internal temperature. Chef's Prime™ loin roasts were found to be "major" sources of vitamin B-6, thiamin, zinc, and selenium and a "good" source of iron.

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Utilization of Twin Screw Cold Extrusion to Manufacture Restructured Chops from Lower-Valued Pork

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Restructured meat products are commonly manufactured by using lower-valued meat trimmings reduced in size by comminution (flaking, chunking, grinding, chopping or slicing). The comminuted meat mixture is mixed with salt and water to extract salt-soluble proteins. These extracted proteins are critical to produce a "glue" which binds muscle pieces together. These muscle pieces may then be reformed to produce a "meat log" of specific form or shape. The log is then cut into steaks or chops which, when cooked, are similar in appearance and texture to their intact muscle counterparts.

Two concerns must be addressed in the manufacture of restructured meat products: texture, and the removal and degradation of connective tissue. Lower-valued meat trimmings used in restructuring tend to contain more connective tissue which may affect product texture.

Mechanical desinewing is used to remove connective tissue from boneless meat trimmings. Reducing the connective tissue in trimmings increases their value for use in various restructured meat products. The method of comminution also affects the final product texture, which usually is somewhere between that of ground (hamburger) and an intact muscle (steak or chop) meat product.

Recently, twin screw cold extrusion has been used as a processing technology to produce restructured meat products. In this process, a comminuted meat mixture is forced to flow through an enclosed twin-screw extruding horn to form "extruded ropes" of a specific shape and size. These ropes can be pressed together to form meat logs which then can be cleaved into restructured steaks or chops. This process is believed to partially realign muscle fibers and modify the texture of meat products.

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This study sought to evaluate various mixing times and extrusion speeds on the sensory and textural attributes of cold extruded restructured pork chops.

Materials and Methods

Manufacturing. Fresh, boneless pork blade loin meat and desinewed pork shank meat were obtained from a commercial source. Blade meat was coarse ground using a 1" plate and the pork shank meat was desinewed to produce comminuted meat trimmings with a diameter of 3/16 in. Batches (70% blade and 30% shank meat) were preweighed (13.6 kg) and held in a cooler at 36°F for 24 hours before mixing.

Salt (0.25%) and sodium tripolyphosphate (0.5%) were added to all extruded pork chop treatments. The meat blocks were mixed in a paddle-mixer for 20 or 40 minutes. Salt and sodium tripolyphosphate were added during the initial mixing period (within 1 min of start time). The mixed meat blocks were bagged in polyethylene, labeled, placed in tubs and stored in a cooler (36°F) until they were extruded.

Extrusion. A Wenger TX 52 twin screw extruder with a screw configuration, consisting of 3/4" pitch screws, 1/2" pitch screws, cone screws, circular locks and shearlocks was used. The twin screws moved in a co-rotating motion as the meat mixture was conveyed through a 1/2" diameter circular extruder horn equipped with a cold water jacket maintained at 36°F. Extrusion speeds of 200, 300 and 400 rpm were used to produce extruded "ropes" which were placed on stainless steel trays lined with polyethylene. Product was frozen for 6 hours at -10°F then tempered for 12 hours at 26°F.

Approximately 12-15 tempered, extruded ropes were pressed into large diameter logs resembling a boneless pork loin roast. The logs were cleaved into 1" thick chops, vacuum sealed in commercial film and stored at -20°F for two weeks before analysis. Boneless pork loin chops from the center loin were chosen for the control. Chops (1" thick) were removed from the center loin, trimmed of all visible subcutaneous fat, packaged and stored in the same manner as the extruded pork chops. Fresh extruded and control chops were evaluated for proximate composition (moisture, fat, protein and ash) and color (lightness, redness and yellowness).

Cooking Procedures and Analyses. Extruded and control pork chops were tempered at 32°F for 12 hours and cooked on a flat-top grill pre-heated to 350°F. Extruded and control chops were cooked to an internal temperature of 160°F and blotted with paper towels after cooking to remove excess grease. Four control chops and four extruded chops from each treatment were evaluated for cooking yield, cooked color and proximate composition. Cooked control and extruded chops were compressed to 25% of original chop height with an Instron Universal Testing Machine. A two-cycle compression was used and values from the compression curves were used to calculate hardness (peak force of compression cycle 1), cohesiveness (area under curve 2 / area under curve 1), springiness (width of compression cycle 2) and chewiness (hardness x cohesiveness x springiness). Tenderness of extruded and control pork chops were determined using a L.E.E.-Kramer shear apparatus attached to the Instron.

Cooked control and extruded pork chops were cut into 1/2-inch cubes and served warm to a consumer sensory panel. Samples were evaluated for texture, flavor, juiciness and overall acceptability on an eight-point hedonic scale where 1=extremely undesirable and 8=extremely desirable.

Scanning Electron Microscopy. Scanning electron microscopy was used to determine the degree of muscle fiber alignment of cooked extruded and control chops. Cryofractured samples (1/16 in cubes) were fixed in a 1.25% glutaraldehyde solution (12-16 hr), washed (2X) in a buffered (pH 7.4) solution and post-fixed (1 hr) in 1% osmium tetroxide. Samples were serially dehydrated in graded ethanol, critical point dried, mounted and sputter-coated with 300 angstroms of gold/palladium. An accelerating voltage of 10 kilovolts and a 100 micron aperture were used to obtain scanning electron micrographs at magnifications from 100-400X.

Statistical Analysis. Data were analyzed as a 2 x 3 factorial arrangement of treatments in a randomized complete block design. Mixing time (20 or 40 minutes) and extrusion speed (200, 300 or 400 rpm) were the main effects. Significant effects were defined to be those with $P<.05$. Means were separated using Fisher's Least Significant Difference (LSD) test.

Results

Differences due to extrusion speed, mixing time or the combined effect of extrusion speed and mixing time were not significant for any of the variables tested. Raw and cooked control chops had more moisture and protein than extruded chops (Table 1). Extruded chops (raw and cooked) had more fat and ash than control chops.

Extruded chops were formulated with 70% blade meat which contained 29% fat, explaining the difference in fat content between the extruded and the control chops. Differences in ash content were probably due to addition of salt and phosphate in extruded chops. Cooking yields (Table 1) were greatest for the 20 min/200 rpm and 40 min/400 rpm extruded chops (74.17 and 75.75%, respectively) and least for 40 min/200 rpm extruded chops and control chops (71.84 and 72.43%, respectively).

Raw and cooked control chops were lighter in color than extruded chops (Table 2). Raw extruded chops were redder and more yellow than control chops. These color differences may be due to the darker lean color contributed by the blade and shank meat used to formulate extruded chops compared to the lighter colored longissimus muscle of control chops. After cooking, this relationship changed.

Cooked control chops were redder and more yellow than extruded chops. Dispersion and amount of fat particles in extruded chops may be responsible for the color differences observed.

Sensory scores for each extruded

Table 1. Effect of mixing time (min) and extrusion speed (rpm) on proximate composition and cooking yields of cold, extruded, restructured pork chops.

	Treatments[a]							
Variable	20 min/ Control	40 min/ 200 rpm	20 min/ 200 rpm	40 min/ 300 rpm	20 min/ 300 rpm	40 min/ 400 rpm	400 rpm	S.E.[b]
Raw								
Moisture, %	67.82*	62.57	61.77	62.00	61.34	62.36	62.24	1.34
Fat, %	10.35**	20.12	21.60	21.11	22.08	20.92	19.45	1.69
Protein, %	22.53**	17.35	16.78	16.82	16.70	16.79	17.34	0.59
Ash, %	1.01**	1.32	1.27	1.31	1.52	1.38	1.37	0.04
Cooked								
Moisture, %	56.8*	53.8	52.3	52.0	53.2	52.6	51.9	1.30
Fat, %	12.5**	25.1	24.5	23.7	23.9	24.4	24.4	2.07
Protein, %	31.1*	22.6	22.3	23.5	22.0	22.1	22.6	0.63
Ash, %	1.20**	1.77	1.80	1.78	1.78	1.81	1.69	0.70
Cooking Yield								
Yield (%)	72.43[cde]	74.71[ef]	71.84[cd]	70.59[c]	75.20[ef]	74.32[def]	75.75[f]	0.80

[a]Control = boneless loin chops; Treatments: mixing time = 20 or 40 min; extrusion speed = 200, 300 or 400 rpm.
[b]S.E. = Standard Error
[cdef]Treatments with different superscripts differ (P<.05)
*The control is significantly different from extruded chops (P<.05).
** The control is significantly different from extruded chops (P<.01).

Table 2. Effect of mixing time (min) and extrusion speed (rpm) on raw and cooked color of cold, extruded, restructured pork chops.

	Treatment[a]							
Variable	20 min/ Control	40 min/ 200 rpm	20 min/ 200 rpm	40 min/ 300 rpm	20 min/ 300 rpm	40 min/ 400 rpm	400 rpm	S.E.[b]
Raw Color								
"L"[c]	41.0*	47.9	50.0	47.2	48.9	47.2	50.1	1.15
"a"[d]	12.8*	19.9	21.6	23.2	21.6	21.7	22.3	12.8
"b"[e]	3.4*	6.5	6.9	6.6	6.7	6.4	6.7	0.07
Cooked Color								
"L"	39.8*	32.2	32.5	29.8	32.7	33.6	32.6	1.06
"a"	16.8*	12.4	13.3	13.3	13.9	12.2	14.0	0.35
"b"	9.32*	6.64	7.33	6.63	7.32	7.07	7.25	0.26

[a] Control = boneless loin chops; Treatments: mixing time = 20 or 40 min; extrusion speed = 200, 300 or 400 rpm.
[b] S.E. = Standard Error.
[c] Lightness Scale: 100 = White, 0 = Black.
[d] Redness: Larger number indicates more red.
[e] Yellowness : Larger number indicates more yellow.
* Control was different from extruded chops (P<.01).

Table 3. Effect of mixing time (min) and extrusion speed (rpm) on sensory and textural attributes of cold, extruded, restructured pork chops.

	Treatment[a]							
Variable	20 min/ Control	40 min/ 200 rpm	20 min/ 200 rpm	40 min/ 300 rpm	20 min/ 300 rpm	40 min/ 400 rpm	400 rpm	S.E.[b]
Sensory Attributes[c]								
Juiciness	4.5*	6.7	6.5	6.5	6.4	6.5	6.3	0.13
Texture	5.1*	5.8	5.8	6.0	5.7	5.8	6.0	0.17
Flavor	5.4*	6.4	6.3	6.3	6.0	6.1	6.1	0.16
Overall Acceptability	4.9*	6.2	6.0	6.1	5.9	6.0	6.0	0.17
Textural Attributes								
Hardness[d]	415.13*	139.50	117.25	118.75	133.88	126.13	133.5	9.72
Cohesiveness[e]	0.43*	0.28	0.29	0.29	0.28	0.28	0.28	0.03
Springiness[f]	15.13*	19.00	19.63	19.00	18.63	19.50	18.88	0.58
Chewiness[g]	2693.16*	744.63	675.33	649.43	695.83	694.16	698.79	92.87
Shear Force (kg/g)[h]	8.54*	4.23	4.63	5.45	4.60	4.77	4.91	0.34

[a]Control = boneless loin chops; Treatments: mixing time = 20 or 40 min; extrusion speed = 200, 300 or 400 rpm.
[b]Standard Error
[c]Sensory Scale: 1 = Extremely undesirable, 8 = Extremely desirable.
[d]Peak Force (kg / gram of compression cycle 1 (CC1).
[e]Area Under the Curve (AUC) of Compression Cycle 2 (CC2)/ AUC of CC1
[f]Width of CC2 (mm).
[g]Hardness * Cohesiveness * Springiness (kg * mm / gram of sample)
[h]Kilogram force per gram of sample
* The control is significantly different from extruded chops (P<.01).

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Figure 1. Micrograph of cooked extruded pork chop sample (20 min/200 rpm). Muscle fibers (a) appear to be aligned. Arrow points to fat globule. Bar scale = 25 microns.

Figure 2. Micrograph of cooked extruded pork chop sample (40 min/ 400 rpm). Arrow points to muscle fibers. Bar scale = 100 microns.

Figure 3. Micrograph of cooked extruded pork chop sample (40 min/ 200 rpm). Linearly arrayed muscle samples (a), possible single muscle fiber (b), and an area of emulsion-like, less ordered fibers (c) are identified. Bar scale = 100 microns.

Figure 4. Linearly arrayed muscle fibers of a cooked, intact muscle boneless pork chop control. Bar scale = 100 microns.

pork chop treatment and control chops are reported in Table 3. Scores for extruded pork chops were greater than control chops for sensory juiciness, texture, flavor and overall acceptability. Greater fat content (24%) in extruded chops compared to control chops (12.5%) may be responsible for this difference. Extrusion has been hypothesized to increase textural properties in restructured products by possibly realigning the muscle fibers of comminuted meat particles to form a more structured arrangement of muscle fibers, similar to that of intact whole muscle. This might explain the higher textural scores for extruded chops.

Control chops were harder and chewier than the extruded chops (Table 3). Extruded chops were springier, less cohesive and required less peak force to shear than control chops. This again may be caused by the higher fat content in extruded chops, resulting in less extracted myofibrillar protein available for protein-protein interactions associated with meat binding, a direct influence on product texture and success of a restructured product.

Scanning electron microscopy was used to determine the degree of muscle fiber alignment of cooked extruded and control chops. Figure 1 is a micrograph from an extruded pork chop sample mixed for 20 min and extruded at 200 rpm. The sample appears to contain

areas of partially realigned, somewhat linearly arrayed muscle fibers. Figure 2 shows a 40 min, 400 rpm extruded pork chop sample also containing slightly realigned muscle fibers with areas that appear to contain emulsion-like, less-ordered material. This emulsion-like material is probably the desinewed pork shank meat which filled in the gaps between muscle fibers during the restructuring and extrusion process. The apparent non-realignment of the muscle fibers of desinewed shank meat may be explained by its smaller particle size (1/4" in diameter) compared to the diameter (1/2") of the extruding horn. Particle sizes smaller than the diameter of the extruding horn may not be forced to flow in a "one way" direction resulting in little realignment of muscle fibers.

Figure 3 is a micrograph from a 40 min, 200 rpm extruded pork chop sample which indicates distinct areas of linearly arrayed muscle fibers composed of chunked pork loin blade meat and emulsion-like, less-ordered areas containing desinewed pork shank meat. Figure 4 shows the well-ordered muscle fiber structure of an intact boneless pork chop control.

Conclusion

Twin screw cold extrusion technology can be used to manufacture restructured meat products. Extruded pork chops manufactured from lower-valued pork loin blade meat and desinewed pork shank meat had desirable sensory and textural attributes which were equal to or better than the intact boneless pork chop control. Scanning electron microscopy of cooked extruded and control pork chop samples suggest that part of the reason for the desired textural attributes observed in extruded chops may be due to partial realignment of muscle fibers.

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Pharmacological Levels of Zinc in Nursery Diets - A Review

Duane E. Reese[1]

Zinc plays significant roles in pig nutrition and health. A zinc deficiency is manifested by skin lesions known as parakeratosis; poor feed intake; slow growth; diarrhea; and atrophy of the thymus, a gland important in immunological competence. Zinc ions may interact with *E. coli* by inhibiting the ability of *E. coli* to respire and therefore reducing its activity. In addition, recent University of Nebraska research indicates that zinc ions cause the organism responsible for swine dysentery (*S. hyodysenteriae*) to produce less toxin. On the other hand, too much zinc in the feed will cause growth depression, arthritis, and ultimately death.

Nutritionists typically add 100 to 150 ppm of zinc to nursery diets to meet requirements for growth. Recently there has been interest in feeding nursery pigs diets containing 2,000 to 4,000 ppm of zinc to combat postweaning stress and diarrhea.

A summary of research studies that have evaluated the response of nursery pigs to pharmacological levels of zinc is presented in Table 1. Added zinc levels ranged from 2,400 to 3,200 ppm. In all cases zinc oxide supplied the supplemental zinc. Percent changes in daily gain, daily feed intake, and feed/gain due to the pharmacological levels of zinc are shown along with the significance level.

This summary indicates that the response to pharmacological levels of zinc is highly variable. For example, sometimes daily gain was increased by 25% whereas at other times gain was decreased by 28% compared to the control diets containing normal zinc concentrations. Similar wide ranges in response to zinc are evident with feed intake. When the incidence of diarrhea was measured, the additional zinc seemed to reduce the frequency of diarrhea.

The level of copper in the diet does not seem to have a consistent effect on the response to zinc. Large positive responses to zinc were observed at all levels of added copper, but more frequent positive responses were observed when dietary copper was low (8 to 22 ppm). Moreover, all the poor responses to zinc were observed when 200 to 250 ppm copper was added to the feed.

These results indicate that the decision to use pharmacological levels of zinc in nursery diets should be made on a case-by-case basis. Careful monitoring of pig performance when high levels of zinc are added to feed is warranted to be sure the right conditions exist for a response. Unfortunately, it is currently not possible to describe the conditions under which a positive response to extra zinc is likely.

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Table 1. Pharmacological Levels of Zinc (Zn) in Nursery Diets—A Summary

Reference	Added Zn, ppm	Zn source	No. pigs	No. pens/treatment	% change from control: Duration, d	% change from control: Daily gain	% change from control: Daily feed	% change from control: Feed/gain	Comments
Poulsen, 1989	2500	ZnO	72	36	7 to 21	+16[A]	+10	-6	Reduced incidence of diarrhea; 10 and 180 ppm Cu added
Holm, 1990	2400	ZnO	120		14	+2	+2	0	Herd diagnosed with E. coli; No. pigs with severe diarrhea reduced
Holm, 1990	3200	ZnO	544		14	+16[A]	+13	-3	Herd diagnosed with E. coli; Mortality reduced from 2.2 to .7%
Tokach, 1992	3110	ZnO	180	5	14	0	+2	+4	200 ppm Cu added
Tokach, 1992	3110	ZnO	168	3	14	-1	+3	+6	200 ppm Cu added
Fryer, 1992	3000	ZnO	18	3	21	+25	+26	0	22 ppm Cu added
Fryer, 1992	3000	ZnO	18	3	21	+25	+21	-7	284 ppm Cu added
Hahn, 1993	3000	ZnO	60	6	21	+14[B]	+13[B]	0	8 ppm Cu added
Hahn, 1993	3000	ZnO	60	6	14	+12[B]	+13[B]	-1	8 ppm Cu added
Master Mix, 1993	3000	ZnO	70	7	14	-13[C]	-3	+11[C]	250 ppm Cu added
Master Mix, 1993	3000	ZnO	70	7	14	+12[C]	+6	-8	12 ppm Cu added
Master Mix, 1993	3000	ZnO	70	7	14	-28[B]	-26[B]	+3	200 ppm Cu added

[A]P<.01
[B]P<.05
[C]P<.06
Results within the boxes are from the same test. Cu = copper.

It is important to know whether positive responses to zinc are occurring on the farm. Otherwise, the practice of feeding extra zinc should be stopped because producers may be taking unnecessary risks, including causing pig performance to decline. Zinc is a heavy metal and it is not known how long-term application of manure from animals fed extra zinc will affect plants or the environment in general. Also, the effect on lagoon function is uncertain. Furthermore, high levels of zinc may interfere with iron metabolism so it is not clear what changes, if any, in iron fortification of diets is necessary.

Recommendations

There obviously can be benefits to feeding pharmacological levels of zinc to nursery pigs. However, until further research is conducted to determine the conditions under which a positive response to pharmacological levels of zinc is likely, the performance of pigs fed high zinc levels be closely monitored. The best way to do this is to conduct an on-farm trial. Details on how to conduct an on-farm feed trial properly are available in the University of Nebraska publication *Conducting Pig Feed Trials on the Farm* (EC 92-270-B). Single copies are available for $.50 at any extension office in Nebraska. Out of state residents should contact Bulletins, P.O. Box 830918 Lincoln, NE 68583-0918.

It is important that the extra zinc be supplied by zinc oxide until further research with other sources is reported. Add 2,500 to 3,000 ppm (7.0 to 8.3 lb of zinc oxide/ton of complete feed assuming the zinc oxide contains 72% zinc) to feed for 14 d postweaning only. Add 6 to 15 ppm copper to the diet.

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Environmental Contamination is a Major Contributor to Prevalence of *Serpulina hyodysenteriae* Infection of Swine on Farms Medicating Against Swine Dysentery

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Swine dysentery is a highly contagious diarrheal disease of growing and finishing swine causing estimated losses of more than $2.4 million monthly to Iowa pork producers.

The spiral-shaped spirochete bacterium, *Serpulina hyodysenteriae*, is routinely identified by bacteriologic culture of intestinal specimens of swine affected with the disease. Specific differentiation of *S. hyodysenteriae* from other bacteria normally present in the intestines of swine is now possible with the use of a nucleic acid-based test developed by scientists in the Department of Veterinary & Biomedical Sciences at UN-L. The test can detect very low numbers of *S. hyodysenteriae* directly in the stools of swine by a process known as polymerase chain reaction (PCR).

We are investigating alternative ways to reduce the economic losses due to swine dysentery. *Serpulina hyodysenteriae* is known to occur outside the pig; however, it is not clear how this affects persistence of the disease on swine farms. Also, house mice (*Mus musculus*) have been shown to be involved in the spread of*S. hyodysenteriae* on farms with swine dysentery, but the spirochete bacterium of mice has not been conclusively identified as *S. hyodysenteriae*. Developing more effective control strategies for swine dysentery requires a more complete understanding of the factors involved in persistence of the spirochete bacterium in pigs and in habitats other than its natural host.

Serpulina hyodysenteriae strains belong to a species of bacteria with many shared characteristics; however, it is possible to distinguish variants within the species using specialized methods. One of these methods uses enzymatic digestion of deoxyribonucleic acid (DNA) obtained from closely related bacterial strains to compare them to each other. This method takes advantage of small differences in the DNA of individual strains to produce patterns of DNA banding or "DNA fingerprint" after separation of the DNA fragments by gel electrophoresis. DNA fingerprinting has become a method of choice for studies aimed at comparing organisms taken from different backgrounds and understanding the spread of disease-causing bacteria.

The objectives of this work were: (i) Determine the relationship between persistence of *S. hyodysenteriae* on farms with swine dysentery and the presence of *S. hyodysenteriae* in pigs, the environment, and house mice on the same farm; and (ii) confirm the presence of *S. hyodysenteriae* outside of its natural host using the PCR test.

Study Design

A cross-sectional study of four midwestern confinement-rearing swine operations with a history of swine dysentery was begun in 1991. The farms were identified on the basis of positive isolations of *S. hyodysenteriae* from the intestines of pigs submitted to the Veterinary Diagnostic Center-Lincoln for laboratory investigations. Each farm was visited and data pertinent to disease status, building design, management practices, and production records was collected. Stool samples from pigs with or without diarrhea at all stages of production, and manure samples from floors and gutters were collected. House mice were captured with multiple-catch mouse traps placed in and around farm buildings.

Each specimen was processed for bacteriologic culture and isolation of spirochetes by conventional methods. Cultures that were positive for the presence of spirochetes were subcultured to purity. Total DNA from representative strains of each source on each farm were examined using the *S. hyodysenteriae*-specific PCR test, and compared with each other by DNA fingerprinting. Recovery rates and DNA fingerprint patterns of *S. hyodysenteriae* were correlated with the source of isolation on each farm.

Results and Discussion

Pertinent management and medication practices for each farm are summarized in Table 1. Farm A was visited once in March, 1992 and again in July, 1992. Farm A and farm B were totally confined operations with ongoing swine dysentery in spite of continuous medication for the past 10 and 6 years, respectively. Farm C had lost a sow, 2 gilts, and approximately 30 piglets to swine dysentery in the month preceding our first visit in January, 1992.

The severity of the clinical problem was significantly reduced, 6 months later at our second visit, by cleaning and disinfecting the premises,

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Table 1. Management and medication practices on farms affected with swine dysentery.

Farm	Management	Number of animals	Stage of production	Medication		
				Feed†	Water‡	Parenteral§
A	Farrow/finish	330-sow	Grower	Carbadox	None	Tylosin
			Finishing	Lincomycin Tiamulin		
B	Farrow/finish	170-sow	Nursery	Carbadox Arsanilic acid	None	None
			Grow/finish	Tiamulin		
C	Farrow/feeder	60-sow	Grower	Carbadox	Tiamulin	Lincomycin
D	Finisher	350-pigs	Finish	Tiamulin	Gentamicin	None

† Inclusion rates as follows: carbadox = 50/t; lincomycin = 100 g/t; tiamulin = 35 g/t; arsanilic acid = 45 g/t.
‡ Tiamulin = 3.5 mg/lb/day for 5 days; gentamicin = 50 mg/gal for 5 days.
§ Tylosin = 4 mg/lb twice per day for 3 days; Lincomycin = 5 mg/kg for 3 days.

and medicating the pigs (Table 1). This farm consisted of a farrowing house with open dirt lots and sheds for breeding/gestation, and small sheds with outdoor solid concrete slabs for growing pigs. An outbreak of acute swine dysentery was brought under control with medication within a week from visiting farm D in October, 1991 (Table 1). The farm consisted of 11 outdoor pens with solid concrete slabs adjoining a shed. Each pen had groups of 20 to 50 pigs ranging in size from 50 to 200 lbs.

The cumulative results of spirochete isolations from specimens collected on each farm are presented in Table 2. *Serpulina hyodysenteriae* was isolated from swine on three farms, from the environment on all the farms, and from house mice on two farms. Except for a dramatic reduction in the prevalence of *S. hyodysenteriae* in swine at the second visit on farm C, the percentage of *S. hyodysenteriae* isolations were similar on two farms where sampling was repeated at several month intervals.

Table 2. Cumulative spirochete isolation results from specimens collected on farms with swine dysentery.

Farm	Visit	Hemolytic Pattern†	No. Isolations (% Recovery)		
			Pigs	Environment	Mice
A	1	Strong	16 (50.0)	9 (45.0)	0 (0.0)
		Weak	3 (9.4)	1 (5.0)	0 (0.0)
	Total no. specimens examined:		32	20	3
	2	Strong	1 (50.0)	7 (46.7)	0 (0.0)
		Weak	0 (0.0)	0 (0.0)	0 (0.0)
	Total no. specimens examined:		2	15	0
B	1	Strong	0 (0.0)	6 (17.1)	3 (9.7)
		Weak	0 (0.0)	0 (0.0)	0 (0.0)
	Total no. specimens examined:		27	35	31
C	1	Strong	15 (28.8)	5 (41.7)	1 (16.7)
		Weak	1 (1.9)	1 (8.3)	0 (0.0)
	Total no. specimens examined:		52	12	6
	2	Strong	1 (9.1)	7 (53.8)	0 (0.0)
		Weak	0 (0.0)	1 (7.7)	0 (0.0)
	Total no. specimens examined:		11	13	3
D	1	Strong	5 (15.6)	1 (5.0)	0 (0.0)
		Weak	1 (3.1)	0 (0.0)	0 (0.0)
	Total no. specimens examined:		32	20	3

†A strong hemolytic pattern suggests *Serpulina hyodysenteriae* whereas a weak hemolytic pattern suggests spirochetes distinct from *S. hyodysenteriae*.

The prevalence of *S. hyodysenteriae*-shedding in pigs ranged from 0% on farm B to 50% on farm A. Because pigs on each farm were medicated for swine dysentery, factors other than medication appeared to affect the pattern of *S. hyodysenteriae* shedding by the pigs. Low *S. hyodysenteriae* shedding in swine from farm B and farm D together with low environmental contamination suggested that the environment may be a major contributor to reinfection of medicated pigs. Scraping of floors together with sunlight and dryness appeared to be effective in reducing environmental contamination on farm D.

Although house mice were caught on all the farms, *S. hyodysenteriae* was isolated from house mice only on two farms; one mouse each in the farrowing houses on farm B and farm C, and two mice in a finishing building on farm B (Table 2 and Table 3). Considering the prevalence of *S. hyodysenteriae*-positive mice on farms B and C, sampling of mice on farms A and D might have been insufficient to demonstrate *S. hyodysenteriae* in the mouse populations on those farms. Mice infected with *S. hyodysenteriae* are known to transmit the disease to pigs by contaminating feedstuffs with their stools. Although, the prevalence of mice carrying *S. hyodysenteriae* was small, rodent control should continue to be an essential part of swine dysentery control and eradication.

Spirochetes that are weakly hemolytic by culture are known to be different from *S. hyodysenteriae*, and some of these spirochetes are associated with a diarrheal disease of swine different from swine dysentery and designated porcine colonic spirochetosis. The weakly hemolytic spirochetes isolated from pigs on farm D and from pigs and the environment on farm A and farm C were not characterized further (Table 2). The widespread distribution of weakly hemolytic spirochetes, which can be difficult to differentiate from *S. hyodysenteriae* by conventional culture, emphasizes the usefulness of the PCR test for laboratory confirmation of swine dysentery; none of the weakly

hemolytic strains tested gave positive results in the *S. hyodysenteriae*-specific PCR test (Table 3). Weakly hemolytic spirochetes were not isolated from house mice, suggesting that mice might not be an important source for persistence of these organisms on swine farms.

Geographic variations in the prevalence of different strains of *S. hyodysenteriae*, as well as the presence of different strains of *S. hyodysenteriae* on the same farm can affect the interpretation of antibiotic sensitivity testing and the efficacy of preventative strategies including vaccination with defined antigen preparations. DNA fingerprint analyses indicated only one pattern (pattern A) in all the samples examined (Table 3). This suggested that *S. hyodysenteriae* strains present in different sources on each farm and also between farms in the midwest were highly conserved.

Table 3. Cumulative results of *Serpulina hyodysenteriae*-specific PCR and DNA fingerprint analyses of representative spirochete strains isolated from specimens obtained from farms with swine dysentery.

Farm	Hemolytic Pattern	No.PCR Positive/No. Tested			DNA Fingerprint Pattern/No. Tested		
		Pigs	Environment	Mice	Pigs	Environment	Mice
A	Strong	5/5	1/1	NA†	A/1	A/6	NA
	Weak	0/1	0/0	NA	ND‡/0	ND/0	NA
B	Strong	NA	2/2	1/1	NA	A/6	A/3
	Weak	NA	NA	NA	NA	NA	NA
C	Strong	0/0	1/1	1/1	A/2	A/5	A/1
	Weak	0/1	0/1	NA	ND/0	ND/0	NA
D	Strong	3/3	1/1	NA	A/1	A/1	NA
	Weak	0/0	NA	NA	ND/0	NA	NA

†NA = Not applicable.
‡ND = Not determined.

Conclusions

Results from this investigation provide information on the distribution of *S. hyodysenteriae* on farms with swine dysentery. Environmental contamination appears to be a major contributor to persistence of *S. hyodysenteriae* on swine farms affected with swine dysentery.

Medication of pigs can reduce the prevalence of *S. hyodysenteriae* in the pigs, but successful control and/or eradication of the disease requires cleaning and disinfection of premises and control of rodents. Environmental sampling rather than sampling of medicated pigs may be more accurate for *S. hyodysenteriae* detection when monitoring progress of eradication efforts.

Absence of regional variation in the distribution of *S. hyodysenteriae* strains from different sources on each farm and also between farms suggested that broad control strategies such as strain specific vaccines may be successful in controlling swine dysentery in the midwest.

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Reduced Severity of Disease Associated With Feeding a Pharmacologic Amount of Zinc in a Laboratory Mouse Model of Swine Dysentery

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Swine dysentery is a highly contagious diarrheal disease of growing and finishing pigs which continues to cost an estimated $115.2 million to the United States' pork producers each year. The disease is caused by the spiral-shaped bacterium, *Serpulina (Treponema) hyodysenteriae* and is characterized by severe bloody diarrhea, reduced weight gain and death of susceptible pigs. When introduced in an uninfected herd, the disease quickly becomes established, requiring continuous medication at a cost of more than $8.00 per pig going to market. Although the cause of the disease has been known since the early 1970s, disease control strategies have essentially remained the same; medication of animals with expensive residue-causing antimicrobials and sanitation of premises.

Serpulina hyodysenteriae produces a toxin capable of destroying red blood cells and killing white blood cells that are involved in the pig's immune defense. Production of intestinal damage in animals inoculated with partially-purified toxin suggests that the toxin is involved in the disease. We have shown previously that the production of the toxin by *S. hyodysenteriae*

(Continued on next page)

can be greatly reduced or completely eliminated by adding various amounts of zinc sulfate ($ZnSO_4$) to culture medium used in the laboratory. Based on that result, we hypothesized that dietary zinc compounds could affect the severity of intestinal infection by *S. hyodysenteriae*. Indeed, a group of researchers had noted reduced severity of dysentery in swine fed zinc-supplemented diets, but the benefit of this approach was not evaluated under well-controlled laboratory conditions. The purpose of the present investigation was to assess the prophylactic effect of a pharmacologic amount of different, feed-grade zinc compounds on infection and production of intestinal damage in laboratory mice inoculated with *S. hyodysenteriae*. Laboratory mice were chosen because they have been extensively used as a model to evaluate intestinal damage caused by *S. hyodysenteriae* infection.

Study Design

A basal diet with or without added zinc oxide (ZnO), $ZnSO_4$, or Zn-methionine to a final concentration of approximately 6,000 ppm of Zn^{2+} was fed to a total of 156 mice randomly allocated to 4 treatment groups consisting of 39 mice each. The control and the zinc-supplemented diets were fed for 10 days before oral inoculation of half of the mice in each group either with *S. hyodysenteriae* or sterile medium. Diets were continued for 42 days, while at weekly intervals, the body weights, liver zinc concentrations, presence of *S. hyodysenteriae* in the intestines, and assessment of intestinal damage were determined in 3 mice per group.

Procedures and Statistical Analysis

The concentrations of Zn^{2+} in each feed formulation and in each mouse liver were determined using inductively coupled argon plasma atomic emission spectrometry (ICAP-AES). Results were reported as means $\pm$ one standard error of the mean (SEM) for each feed formulation and for mice from the same treatment group examined on the same post-inoculation day (PID). After determining the body weight of each mouse, a portion of the intestines was processed for histological examination and determination of the length of the intestinal crypts (longitudinal crypt length = LCL).

From these measurements, the mean $\pm$ SEM of body weights and LCL of mice from the same treatment group examined on the same PID were calculated. To determine if supplementation of the basal diet with each zinc compound had an effect on the growth of the mice and the development of intestinal damage associated with *S. hyodysenteriae* infection, the means of the body weights and LCL of mice fed with the basal diet and with the basal diet supplemented with each zinc compound and inoculated either with *S. hyodysenteriae* or medium were subjected to analysis of variance for each weekly sampling from PID 0 to 42. Differences between groups were considered significant if the *P* value of the statistical test was less than 0.05 ($P < 0.05$).

Results

The basal diet contained 42.5 ppm of Zn^{2+}. The mean concentrations of Zn^{2+} were 6,010 $\pm$ 509.8, 6,075 $\pm$ 123.7, and 6,135 $\pm$ 384.7 ppm in the basal diets supplemented with ZnO, $ZnSO_4$, and Zn-methionine, respectively. From PID 0 to 42, the liver zinc concentrations of mice fed the zinc-supplemented diets were approximately twice that of the mice fed the basal diet, irrespective of the source of zinc. Although no significant difference in the mean body weight gain (BWG) was found between mice in the *S. hyodysenteriae*- and the medium-inoculated groups fed with the same diet, a statistically significant difference in the mean BWG was found between mice fed with different diets ($P < 0.05$). The mean BWG of mice fed the basal diet from day 0 to 42 was 9.0 $\pm$ 0.9 g compared with 4.8 $\pm$ 0.6 g and 3.0 $\pm$ 0.3 g for mice fed the basal diet supplemented with Zn-methionine and ZnO, respectively. The mean body weight of mice fed the basal diet supplemented with $ZnSO_4$ did not change between day 0 and day 42 of the experiment. Overall, the mice fed the basal diet had significantly greater mean BWG than did mice fed the zinc-supplemented diets ($P < 0.05$). From PID 7 through 42, *S. hyodysenteriae* was isolated from the intestines of 77.8% of the infected mice fed the basal diet. In contrast, *S. hyodysenteriae* was not isolated from any of the *S. hyodysenteriae*-inoculated mice fed the diets supplemented with either ZnO or Zn-methionine. Of the *S. hyodysenteriae*-inoculated mice fed the $ZnSO_4$-supplemented diet, *S. hyodysenteriae* was isolated from the intestines of 3 of 3 mice examined on PID 7. The overall percentage of *S. hyodysenteriae* isolation from the $ZnSO_4$-supplemented group from PID 7 through 42 was 16.7%.

On PID 14 and 21, mice inoculated with *S. hyodysenteriae* and fed the basal diet had intestinal damage typical of *S. hyodysenteriae* infection. On PID 14, no intestinal damage was present in 3 of 3 mice fed the ZnO-, 2 of 3 mice fed the $ZnSO_4$-, and 1 of 3 mice fed the Zn-methionine-supplemented diet and inoculated with *S. hyodysenteriae*. The remaining mice had mild to moderate intestinal damage similar to that present in mice fed the basal diet. No significant changes were present in the intestines obtained from *S. hyodysenteriae*-inoculated mice fed the zinc-supplemented diets after PID 14, except in one mouse fed the $ZnSO_4$-supplemented diet on PID 35. This mouse had changes similar to those present in mice fed the basal diet. Marked increase in the mean LCL occurred in the intestines of infected mice fed with the basal diet on PID 14 and 21 (Figure 1). Conversely, the mean LCL in the intestines of infected mice fed the zinc-supplemented diets were significantly reduced on PID 14 and 21 ($P < 0.05$).

Discussion

The isolation of *S. hyodysenteriae* from mice fed the basal diet was similar to that reported in previous experiments. In contrast, isolation of *S. hyodysenteriae* and severity of intestinal damage in *S. hyodysenteriae*-inoculated mice fed a pharmacologic amount of dietary zinc were strikingly less than that of mice fed the basal diet

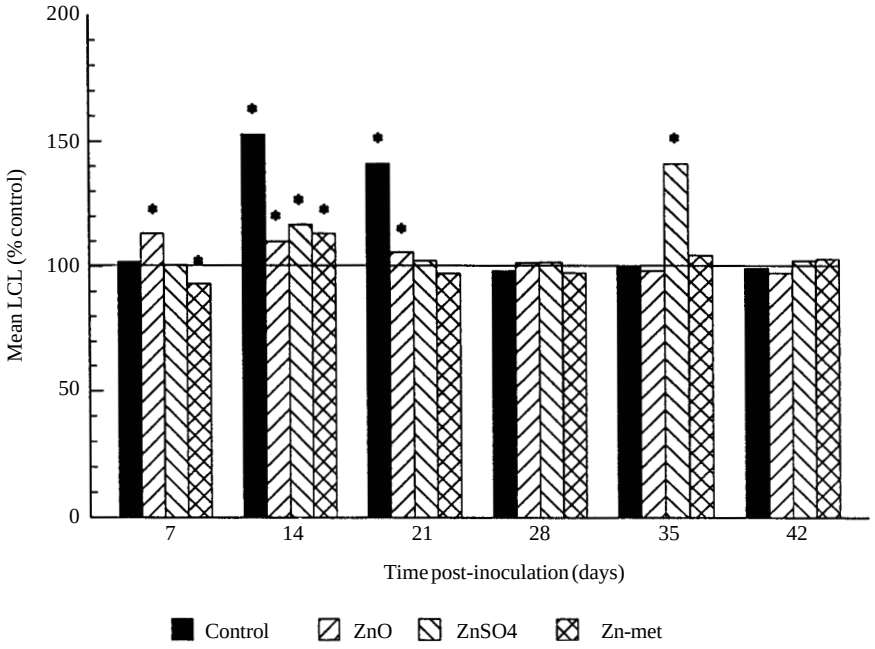

Figure 1. Mean longitudinal crypt length (LCL) in intestine of *Serpulina hyodysenteriae*-inoculated mice expressed as a percent of the mean LCL of the medium-inoculated control mice fed with either the basal diet (control) or the basal diet supplemented with 6,000 ppm of either ZnO, $ZnSO_4$, or Zn-methionine (Zn-met). Each bar represents the percent mean LCL of 3 *S. hyodysenteriae*-inoculated mice against 3 medium-inoculated mice with * indicating statistically significant differences between each group ($P < 0.05$).

alone, irrespective of the source of zinc ($P < 0.05$). However, feeding diets supplemented with approximately 6,000 ppm of zinc had a deleterious effect on the growth of the mice. Because of its antimicrobial activity, $ZnSO_4$ was widely used for treatment of gastroenteritis, diarrhea, and dysentery in human beings before the advent of antibiotics.

Production of toxins by bacteria is an adaptive process which can be induced or repressed in response to changing environments. We have shown previously that approximately 15 ppm of $ZnSO_4$ can inhibit the production of toxin by *S. hyodysenteriae*. Also, addition of approximately 800 ppm of $ZnSO_4$ to culture medium significantly reduces both the production of toxin and the growth of the spirochetes. It is conceivable that reduced isolations of *S. hyodysenteriae* and reduced severity of intestinal damage were due to zinc-induced inhibition of toxin production by the *S. hyodysenteriae*.

Intestinal damage in mice fed the basal diet and infected with *S. hyodysenteriae* were similar to those described previously. Subjective histologic assessment of intestinal damage and measurements of LCL as a quantitative evaluation of intestinal damage confirmed the prophylactic effect of dietary zinc against the development of intestinal damage associated with *S. hyodysenteriae* infection. Of the different zinc compounds, Zn-methionine appeared to have the most significant prophylactic effect. Recurrence of intestinal damage in the absence of positive isolation of *S. hyodysenteriae* in one mouse fed the $ZnSO_4$-supplemented diet on PID 35 suggests that low numbers of spirochetes might have been present in the intestines of mice fed the zinc supplemented diets.

Feeding over 100 times the recommended concentration of dietary zinc for 52 days had a deleterious effect on the BWG of the mice. The effect on the BWG was most pronounced with $ZnSO_4$, but mice fed ZnO and Zn-methionine also gained only about half the weight of mice fed with the basal diet. Based on elevated liver Zn^{2+} and Fe^{2+} concentrations (approximately double that of mice fed with the basal diet, $P < 0.05$) combined with decreased liver Cu^{2+} concentrations (approximately half that of mice fed with the basal diet, $P < 0.05$), we attributed the reduced BWG of mice fed pharmacologic amount of zinc to excessive zinc exposure. Signs of excessive zinc exposure in animals are thought to be those of induced copper deficiency and interference with absorption and utilization of iron.

Different zinc formulations are absorbed by different pathways, and this can result in differences in the bioavailability of the zinc cation. Although very little is known about zinc absorption in bacteria, reduced isolations of *S. hyodysenteriae* and reduced intestinal damage in infected mice fed with Zn-methionine may indicate a greater bioavailability of the zinc-chelate for the spirochetes.

Conclusions

Although the cause of swine dysentery is well known, the disease continues to result in considerable economic losses to commercial swine producers. A vaccine for swine dysentery has been commercially available for many years; but it has not provided the protection anticipated. Researchers have shown that if pigs are allowed to recover naturally from swine dysentery, without medication, they are protected against the disease. Immunity following natural recovery thus can provide adequate protection against swine dysentery. It is conceivable then that protection against swine dysentery can be achieved by inhibiting production of toxin by the spirochetes while the pig's immune system is allowed to build up resistance. Inhibition of *S. hyodysenteriae* toxin by a dietary element such as zinc offers an attractive alternative to continuous medication of animals with expensive, residue-causing antimicrobials.

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Addition of Fat to Diets of Lactating Sows. I. Effects on Sow and Pig Performance

Scott L. Tilton
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Phillip S. Miller
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Sow energy intake during lactation is an important factor to consider when trying to maximize sow and pig performance. It has been shown that inadequate energy intake during lactation results in decreased litter weaning weight. Poor energy intake during lactation is also thought to result in a reduction in postweaning reproductive performance by extending the period from weaning to rebreeding. This reduction in postweaning performance is typically preceded by the excessive loss of weight and backfat during lactation.

One method that has been used to increase sow energy intake, and thus alleviate the problems described above is to add dietary fat. The addition of high concentrations of fat (e.g., 7.5 to 15% of the diet) has been shown to result in increased sow energy intake during lactation, and if consumed for approximately one week before farrowing, increased survival rates for pigs with light birthweights.

This article reports the effects of high fat diets on sow lactation performance, litter performance, and sow feed and energy intake. A subsequent article will discuss the effects of added dietary fat on energy intake, meal patterns, and blood hormones and metabolites. A specific objective of this research was to determine the effects of dietary fat on milk production and composition.

Procedures

Eighteen second parity crossbred sows[2] and 18 first parity sows (gilts) were used in two experiments. Sows and gilts received approximately 4 lb/d of a standard diet throughout gestation.

Sows and gilts were randomly allotted within room (six farrowing crates per room) to receive either a corn-soybean meal or a corn-soybean meal-10% tallow (fat) diet (Table 1). Diets were formulated to contain 1.01% lysine. Levels of other nutrients were included at 110% of the National Research Council requirements. Farrowing room temperature was maintained at 75°F, with continuous lighting. Sow and litter weights were recorded on a weekly basis from day 0 (within 24 h postfarrowing) to day 28. Feed intake was determined daily for 21 days. Litter size was standardized within 3 days after farrowing. Sow backfat thickness was measured at time of weighing using B-mode ultrasound. Milk production was estimated by weighing pigs before and after nursing for a period of 12 h using four sows on day 18 and four sows on day 19 of lactation. Immediately after estimation of milk production on day 18, milk samples were taken from all sows by manual expression from the gland. Milk samples were analyzed for their contents of dry matter, energy, protein, fat, and fatty acids. Data were analyzed as a randomized complete block experiment, with sows and gilts blocked by room and experiment.

Table 1. Composition of diets

Ingredient, %	Control	10% Tallow
Corn	66.15	55.00
Soybean meal (44% CP)	29.85	30.95
Limestone	.40	.30
Dicalcium phosphate	2.00	2.15
Salt	.50	.50
Vitamin premix	1.00	1.00
Trace mineral premix	.10	.10
Tallow	0	10.00
Formulated composition		
Protein, %	18.5	18.0
Metabolizable energy, Mcal/lb	1.46	1.67
Lysine, %	1.01	1.01
Calcium, %	.90	.90
Phosphorus, %	.75	.75

Results and Discussion

Analyzed values for the diets in each experiment were similar to predicted values (Tables 1 and 2). Values also exceeded the National Research Council requirements for all nutrients. Fatty acid compositions of experimental diets are provided in Table 3. Analyzed relative fatty acid percentages were greater for the 10% tallow diets with the exception that both linoleic and linolenic acid were higher in the control diets.

Feed intake was excellent (especially in the gilts) and there were no differences ($P > .10$) in feed intake due to diet for either sows or gilts. However, sows and gilts that consumed the high fat diet had slightly less feed intakes than the respective groups that consumed the control diet. No differences were detected for sow weight loss from farrowing to weaning in either experiment (Table 4). Sows that consumed the high fat diet gained .18 inches of

Table 2. Analyzed composition of diets

	Gilts		Sows	
Criteria	Control	10% Tallow	Control	10% Tallow
Dry matter, %	89.8	89.8	90.0	90.6
Protein, %	19.44	18.27	19.23	18.98
Lysine, %	1.01	.95	.93	.96
Gross energy, Mcal/lb	1.77	1.98	1.80	2.01
Fat, %	2.54	11.46	2.71	11.70
Calcium, %	.95	.89	.93	.90
Phosphorus, %	.76	.72	.77	.75

Table 3. Fatty acid composition of the diets[a]

	Gilts		Sows	
Fatty acid, %	Control	10% Tallow	Control	10% Tallow
Myristic (14:0)	0	.75	0	.71
Palmitic (16:0)	2.12	9.42	2.26	8.23
Palmitoleic (16:1)	0	.69	0	.69
Stearic (18:0)	.33	5.77	.36	4.61
Oleic (18:1)	2.60	11.19	2.68	10.88
Linoleic (18:2)	94.55	71.79	94.46	74.69
Linolenic (18:3)	.40	.21	.24	.18

[a] Data are presented as a percentage of the fat present in the sample.

Table 4. Summary of sow and pig performance and milk composition

	Gilts		Sows	
Criteria	Control	10% Tallow	Control	10% Tallow
Feed intake, lb/d	13.40	12.10	13.98	13.25
Energy intake, Mcal ME/d[a]	19.569	20.110	20.405	22.015
Lysine intake, g/d[a]	61.41	52.16	58.96	57.70
Sow weight change, lb				
d 0 to 21	-2.57	-6.65	-8.38	.37
d 0 to 28	-1.82	-11.01	-11.13	-5.82
Sow backfat change, in.				
d 0 to 21	-.12	-.08	-.08[b]	.18[c]
d 0 to 28	-.09	-.13	-.07	.06
Litter size at birth[d]	11.33	11.22	10.33	10.44
Litter size at d 21	9.63	9.25	9.56	9.78
Litter weight gain, lb[e]				
d 0 to 21	91.21	91.58	103.40	103.40
d 0 to 28	119.93	122.03	146.03	148.66
Milk yield, lb/d[e]	17.04	14.54	23.19	25.56
Milk composition				
Percent solids, %	19.36[b]	21.14[c]	19.58[b]	21.17[c]
Percent protein, %	5.32	5.16	5.30	5.10
Percent fat, %	7.66[b]	10.02[c]	7.77[b]	9.11[c]
Percent ash, %	.776	.818	.805	.837
Percent Ca, %[g]	.867	--	.805[b]	.952[c]
Percent P, %[g]	.733	.682	.705	.672
GE, kcal/lb	534.7[b]	622.4[c]	545.4[b]	617.3[c]

[a] Calculated value, not statistically analyzed.
[b,c] Within parity, treatments with unlike superscripts differ, P < .05.
[d] Number of pigs after crossfostering.
[e] Number of pigs nursed was used as a covariate in this analysis.
[f] Milk yield was determined on four animals per parity*treatment classification, using the weigh-suckle-weigh technique.
[g] Expressed as a percentage of solids.

Table 5. Fatty acid composition of milk[a]

	Gilts		Sows	
Fatty acid, %	Control	10% Tallow	Control	10% Tallow
Capric (10:0)	.22[b]	.01[c]	.13[b]	.01[c]
Lauric (12:0)	.20	.17	.21	.20
Myristic (14:0)	2.84[d]	2.57[e]	2.70[d]	2.39[e]
(14:1)	.26	.20	.22	.20
Palmitic (16:0)	18.25[b]	16.48[c]	17.63[b]	14.77[c]
Palmitoleic (16:1)	7.83[b]	4.91[c]	7.07[b]	4.77[c]
Stearic (18:0)	1.78[b]	2.61[c]	1.70[b]	2.08[c]
Oleic (18:1)	12.71[b]	18.45[c]	12.15[b]	16.48[c]
Linoleic (18:2)	55.47	54.32	57.94	58.92
Linolenic (18:3)	.46[b]	.27[c]	.22	.18

[a] Data are presented as a percentage of the fat present in the sample and do not reflect differences in percentage of the milk that is fat. Values in parentheses are chain length:saturated carbons.
[b,c] Treatments with unlike superscripts within parity differ P < .05.
[d,e] Treatments with unlike superscripts within parity differ P ≤ .10.

backfat, whereas control sows lost .08 inches during the first 21 days of lactation (P < .05). However, no differences in backfat loss were detected on day 28 for sows or on day 21 or day 28 for gilts.

There were no differences (P > .10) in litter size at birth or weaning (Table 4). In addition, there were no differences (P > .10) in litter weight gain.

Milk yield determined on days 18 and 19 ranged from 14 to 26 lb per day (Table 4). Although not compared statistically, sows produced 6 to 10 lb per day more milk than gilts. The percentage of solids and fat in milk samples was greater (P < .01) in samples collected from sows and gilts that consumed the high fat diets, resulting in higher gross energy values for milk from sows fed high fat diets. There were also changes in the fatty acid composition of the milk due to diet (Table 5). There were reductions (P < .05) in the percentage of short-chain (C10 to C14) saturated fatty acids in the milk of sows that consumed the 10% tallow diet, with the exception of lauric acid (C12:0). The percentage of palmitic acid (C16:0) was less in the milk of sows that consumed high fat diets.

Conclusions

Lactating sows that consume diets high in fat tend to have a slight reduction in feed intake. This reduction in feed intake is observed even though energy intake increases during lactation, provided that sows are in a thermoneutral environment. This increase in energy intake results in an increase in milk fat percentage. When considered with the milk production estimates, this results in an increase in the amount of fat secreted in milk. Although there was an increase in the energy density of the diet that the pigs received, there were no differences in pig growth performance due to dietary treatment.

Sow weight loss during lactation was not affected by treatment, suggesting that sows in these studies consumed adequate amounts of energy to meet the demands of lactation (Table 4). This is

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also supported by the small amount of backfat lost during lactation, or in the case of the second parity sows fed the 10% tallow diet, an increase in backfat thickness during lactation.

Milk fatty acid composition was altered (Table 5). The increase in oleic (C18:1) and linoleic (C18:2) acid in the milk is a direct response to increased dietary intake of these fatty acids. However, the amount of palmitic acid (C16:0) in the milk decreased even though dietary palmitic acid content increased. In addition, there is a reduction in the percentages of short-chain fatty acids in the milk of sows fed the high tallow diet. This is also indicative of a reduction in fatty acid synthesis in the mammary glands of sows that consumed the high tallow diet. Therefore, more milk fat was derived from dietary origin in gilts or sows fed the 10% tallow diets. The ability to manipulate milk fatty acid content nutritionally is not surprising because the pig is thought to utilize fat proportionally to what is consumed. In addition, it has been shown that dietary fatty acid content has a significant effect on milk composition.

In summary, the addition of 10% tallow to lactation diets resulted in an alteration of milk fat and fatty acid profiles, without significantly altering sow and pig performance during the lactation period. The increase in milk energy observed in sows and gilts consuming the tallow diets has important research applications for investigating the effects of energy intake on litter performance and sow weight loss during lactation.

[1]Scott L. Tilton and Paul M. Ermer are graduate students, Austin J. Lewis is a Professor, Phillip S. Miller is an Assistant Professor, and Cynthia K. Wolverton is a Research Technologist, Department of Animal Science.

[2]Two sows were removed from the experiment on d 19 due to a technical error. Data from these animals appear only in the initial litter information, and milk yield and composition data.

Addition of Fat to Diets of Lactating Sows. II. Effects on Energy Intake, Meal Patterns, and Blood Hormones and Metabolites

Paul M. Ermer
Scott L. Tilton
Phillip S. Miller
Austin J. Lewis
Cynthia K. Wolverton[1]

Suboptimal feed intake during lactation is associated with reduced litter weight gain and increased sow weight loss. This weight loss may lead to a prolonged weaning-to-estrus interval and decreased embryo survival in subsequent parities. Feed intake is a particular concern in primiparous sows, which consume 15% less feed than multiparous sows.

The consequences of low feed intake and excess body weight loss during lactation have received considerable attention. However, little research has focused on the mechanisms that regulate feed intake in the lactating sow. Furthermore, the progress being made in increasing litter size will continue to increase milk production and nutrient demands during lactation.

Numerous researchers have found that adding relatively large amounts of fat to the diet of lactating sows (e.g., 10% of the diet) results in increased energy intake, increased milk fat and energy, and increased litter weight gain. At these levels of fat addition, energy intake is increased by approximately .8% for every 1% addition of fat to the diet. However, adding fat seems to have little effect on reducing lactation weight loss.

Our research sought to identify possible physiological mechanisms whereby energy intake is increased when tallow (fat) is added to the diets of lactating sows.

Methods

Two experiments were conducted using 18 second parity sows and 16 first parity sows (gilts). Sows and gilts were assigned to dietary treatment after parturition. Weights postpartum were 469 and 375 lb for sows and gilts, respectively. A complete description of experimental methods and diets is presented in the preceding article.

Sow and litter weights were recorded weekly throughout the 28-day lactation. Feed intake was determined daily for 21 days. On days 7 and 20 of lactation, meal patterns of 24 sows (12

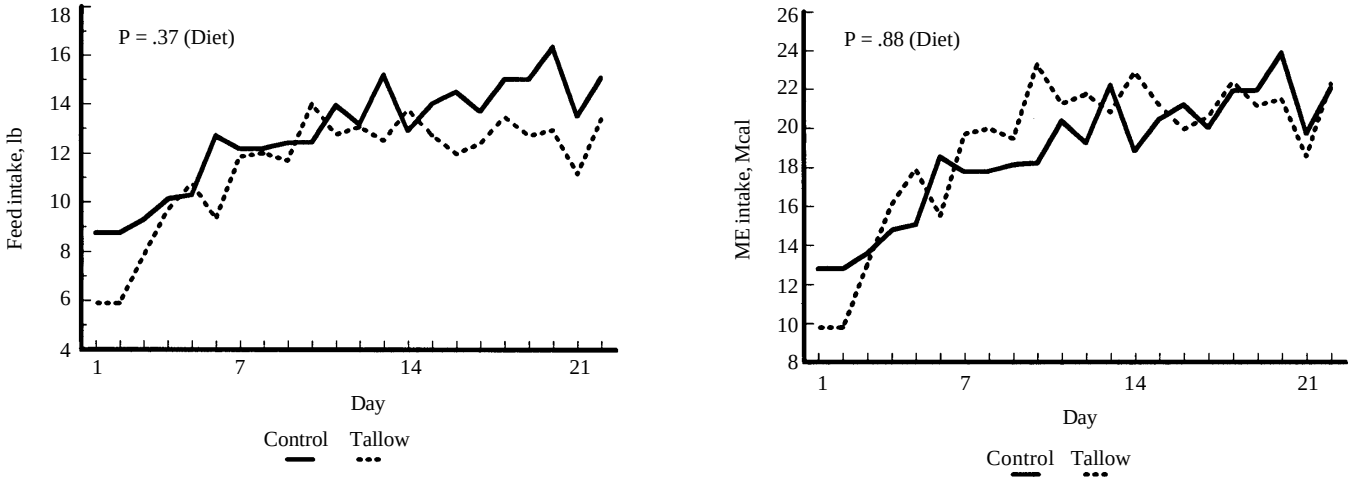

Figure 1. Feed and energy intake of gilts fed either a corn-soybean meal diet or a corn-soybean meal-10% tallow diet throughout a 21-d lactation (n = 16).

sows and 12 gilts) were examined continuously for 24 hours. Time spent eating and time between feedings were recorded and feeders were weighed to determine the amount of feed consumed. Sows were considered to be feeding when observed with their head in the feeder and chewing feed.

For each sow during each 24-hour period, periods of feeding were characterized into meals. Meals were considered to be periods of feeding separated by intervals of relatively short duration (usually 20 minutes or less). These brief and frequent intervals generally represented drinking and other activities associated with the meal. Longer (30 minutes to several hours), and less frequent intervals represented sleeping or other activities. Statistical methods were used to establish whether an interval was categorized as occurring during the course of a meal or between meals.

Feed consumption rate was calculated by dividing intake during the 24-hour observation period by the duration of time spent consuming feed. Similarly, the percentage of time spent consuming feed was obtained by dividing the duration of time spent consuming feed by the total length of the observation period (24 hours).

Fasting (overnight) concentrations of hormones and metabolites were measured on venous blood drawn from all sows on day 109 of gestation and days 9 and 23 of lactation. Blood plasma was analyzed for glucagon (gilts only), insulin, glucose, and nonesterified fatty acids (NEFA).

Results

Daily feed and energy intakes are presented in Figures 1 and 2. There were no differences (P > .3) in either

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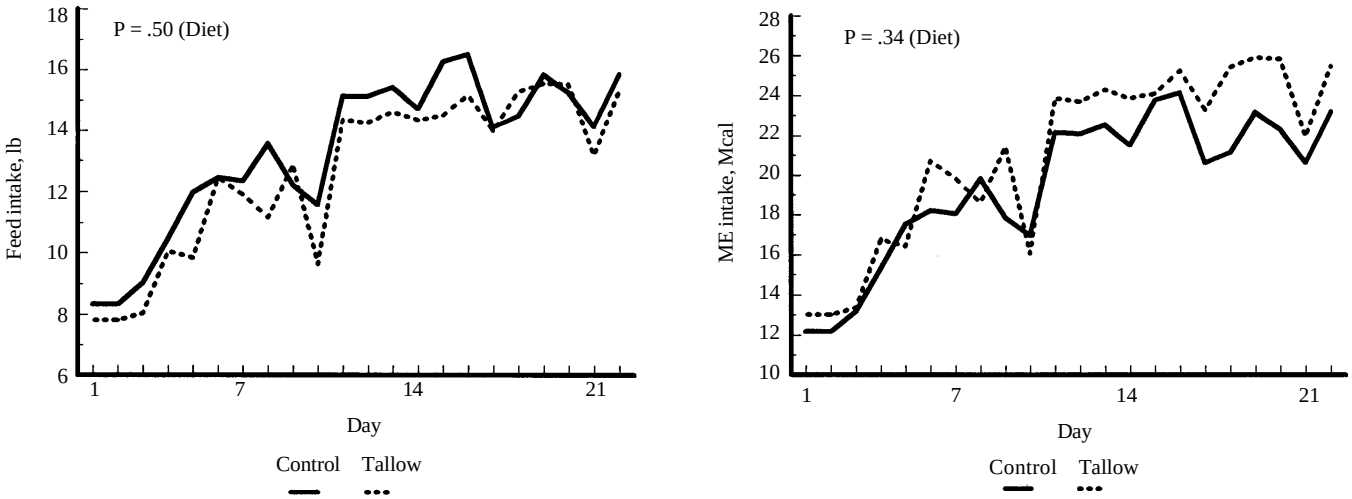

Figure 2. Feed and energy intake of sows fed either a corn-soybean meal diet or a corn-soybean meal-10% tallow diet throughout a 21-d lactation (n = 18).

Table 1. Meal patterns of gilts fed either a corn-soybean meal or a corn-soybean meal-10% tallow diet[a]

Response	Day	Corn-SBM	Tallow	P (Diet)	P (Day)	P (Diet × Day)	SE[b]
Meal size, lb	7	1.68	1.81	.92	.23	.75	.07
	20	2.20	2.12				
Number of meals	7	7.50	7.83	1.00	.34	.69	.44
	20	7.07	6.67				
Rate of consumption, oz/minute	7	1.71	2.45	.08	.93	.44	4.01
	20	1.91	2.19				
Percentage of time consuming feed, %	7	8.92	6.09	.05	.57	.98	.67
	20	9.88	7.00				

[a]n = 22
[b]SE = standard error

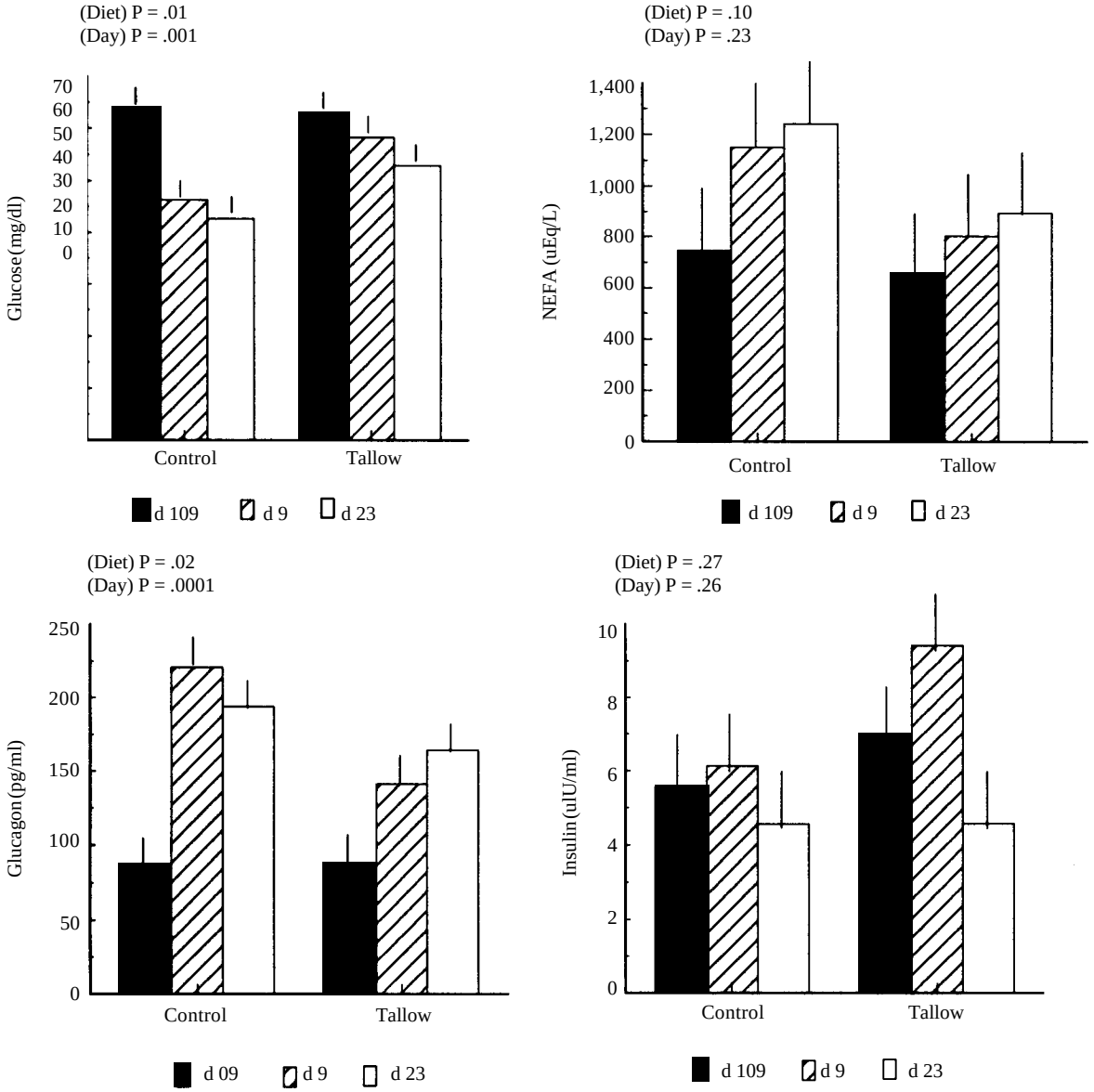

Figure 3. Concentrations of glucose, nonesterified fatty acids (NEFA), glucagon, and insulin in gilts fed either a corn-soybean meal diet or a corn-soybean meal-10% tallow diet throughout a 21-d lactation (n = 16).

Table 2. Meal patterns of sows fed either a corn-soybean meal or a corn-soybean meal-10% tallow diet[a]

Response	Day	Corn-SBM	Tallow	P (Diet)	P (Day)	P (Diet × Day)	SE[b]
Meal size, lb	7	2.76	1.48	.01	.17	.10	.06
	20	2.67	2.31				
Number of meals	7	5.67	8.17	.16	.77	.15	.43
	20	7.17	7.17				
Rate of consumption, oz/minute	7	1.68	2.30	.002	.90	.79	2.68
	20	1.65	2.38				
Percentage of time consuming feed, %	7	10.03	5.86	.0001	.05	.62	.50
	20	12.64	7.44				

[a]n = 24
[b]SE = standard error

feed or energy intake in either sows or gilts. However, in both sows and gilts, adding tallow to the diet resulted in a numerical reduction in feed intake. Sows fed the tallow diet consumed 8% more energy than sows fed the corn-soybean meal diet. In gilts, adding tallow to the diet resulted in a 3% increase in energy intake.

Meal pattern data for gilts and sows are presented in Tables 1 and 2. The addition of tallow to the diet resulted in reduced meal size in sows on day 7 of lactation (Table 2). There were no differences in meal size on day 20 for either gilts or sows. Both sows and gilts that received the tallow diet spent less time (P < .05) consuming feed and had greater rates of feed consumption than those that received the corn-soybean meal diet. (P < .08; Tables 1 and 2).

Blood hormone and metabolite data are presented in Figures 3 to 5. In gilts, feeding the 10% tallow diet resulted in increased (P < .01) fasting concentrations of glucose, reduced (P < .10) NEFA, and reduced (P < .05) glucagon. There were no diet effects (P > .10) on the concentrations of metabolites in sows. However, glucose concentration decreased as lactation advanced in sows fed both the corn-soybean meal and tallow diets. No effects (P > .10) of diet on fasting insulin concentration were observed in either sows or gilts. Although not statistically significant, the insulin to glucagon ratio was higher in gilts fed tallow on d 9 of lactation.

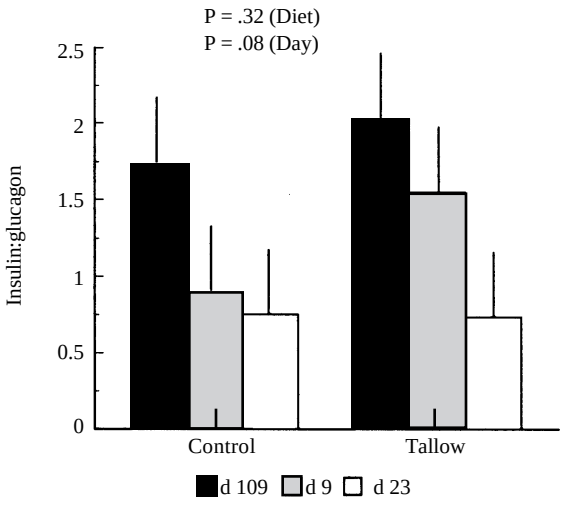

Figure 4. Molar ratio of insulin to glucagon in gilts fed either a corn-soybean meal diet or a corn-soybean meal-10% tallow diet throughout a 21-d lactation (n = 16).

Discussion

The lack of significant differences in either feed or energy intake may have resulted from the thermoneutral environment in these studies. Adequate feed intakes of sows and gilts fed both diets was reflected by minimal weight and backfat loss. The energy intake response to added fat is probably greatest under conditions of heat stress and reduced feed intake.

Although effects of added tallow on meal size and meal frequency were variable, there was a consistent effect of fat on reducing the amount of time spent consuming feed and increasing rate of consumption. Diets that are very palatable are usually consumed more rapidly than diets that are less palatable. The effect of added tallow on diet palatability in lactating sows is still unknown.

Insulin and glucagon are two major metabolic hormones that regulate nutrient flux after the ingestion of meals as well as during fasting. In conjunction with their effects on metabolite utilization, both insulin and glucagon have pronounced effects on feed intake.

An increase in glucagon concentration and a decrease in insulin concentration reflects a fasted state or increased nutrient demand. Previous researchers have observed a reduction in insulin concentration and an increase in glucagon concentration during lactation in sows. In the present study, glucagon concentration was increased during lactation in gilts, but there was no consistent effect of lactation on insulin concentration in either sows or gilts.

The addition of 10% tallow did numerically increase energy intake by 8% in lactating sows. Although there were inconsistent effects of diet on meal

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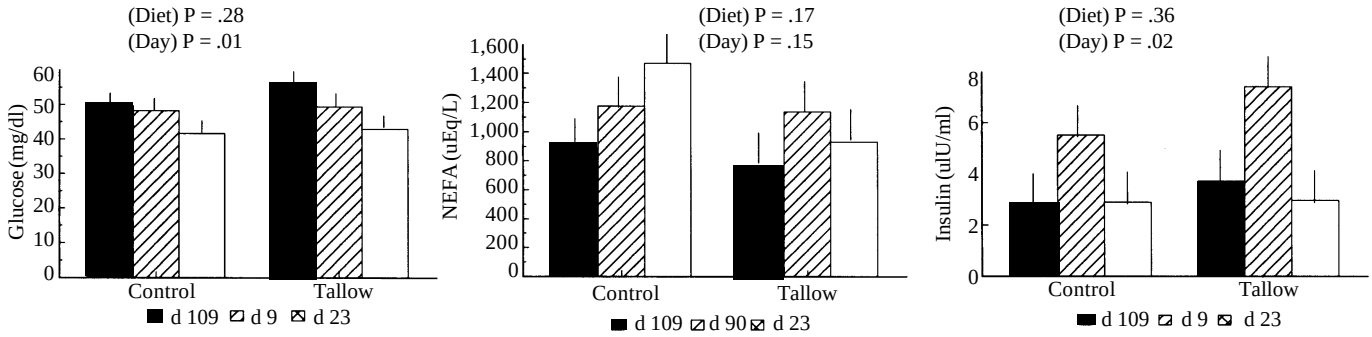

Figure 5. Concentrations of glucose, nonesterified fatty acids (NEFA), and insulin in sows fed either a corn-soybean meal diet or a corn-soybean meal-10% tallow diet throughout a 21-d lactation (n = 18).

size and the number of meals, the addition of fat reduced the percentage of time spent consuming feed and increased the rate of feed consumption.

Because of the importance of insulin and glucagon in the regulation of nutrient utilization and feed intake, further research is warranted. In particular, the effects of dietary energy density on feed intake as mediated by changes in insulin and glucagon will be investigated in future studies.

[1]Paul M. Ermer and Scott L. Tilton are graduate students, Phillip S. Miller is an Assistant Professor, Austin J. Lewis is a Professor, and Cynthia K. Wolverton is a Research Technologist, Department of Animal Science.

Are There Benefits in Adding Fat to Sow Lactation Diets?

Phillip S. Miller
Austin J. Lewis
Cynthia K. Wolverton[1]

Introduction

Lactation is a metabolic challenge to the sow. Some high-producing sows can produce as much as 30 lb of milk/day during peak lactation. Unfortunately, most sows are unable to consume sufficient dietary energy to fuel the processes of milk synthesis and must mobilize body stores of fat and protein. This problem is accentuated as the number of pigs nursed increases (milk production is increased). Therefore, nutritional programs for lactating sows must incorporate strategies to maximize energy intake and avoid excessive weight loss that may contribute to longer rebreeding intervals or increased culling from the sow herd.

Research conducted at the University of Nebraska in the late 1970s and early 1980s examined the relationship between dietary energy intake and sow productivity. These experiments used high fat (tallow; 8 to 10%) additions to create diets that when limit fed would result in different daily energy intakes. Subsequently, the benefits of maximizing energy intake during lactation observed in these studies have been attributed to fat itself. However, because of practical and economic considerations, additions of fat in commercial sow lactation diets are considerably lower than 8% (i.e., 1 to 4%). Therefore, the objective of this study was to examine the effects of practical additions of fat (tallow) on sow energy intake and litter performance during lactation.

Table 1. Composition of experimental diets[a]

	Dietary tallow, %		
Ingredient, %	0	2	4
Corn	65.90	62.90	59.90
Soybean meal, 44% CP	19.75	20.75	21.75
Beet pulp, dried	10.00	10.00	10.00
Dicalcium phosphate	2.75	2.75	2.75
Salt	.50	.50	.50
Trace mineral premix	.10	.10	.10
Vitamin premix	1.00	1.00	1.00
Tallow	0.00	2.00	4.00
Analyses, calculated (%)			
ME, Mcal/lb	1.43	1.47	1.51
Crude protein	15.2	15.4	15.5
Lysine	.80	.82	.84
Calcium	1.01	1.02	1.02
Phosphorus	.83	.83	.83

[a]As-fed basis

Methods

One hundred twenty-two first parity sows raised and bred at the University of Nebraska Swine Research Center at Mead were used in this study. Three dietary treatments (Table 1) were formulated to contain either 0, 2, or 4% added tallow. The corn:soybean meal ratio was adjusted between the three dietary treatments to maintain a constant lysine:metabolizable energy (ME) ratio. Concentrations of other nutrients were formulated to meet or exceed recommendations provided in the

University of Nebraska Swine Diet Suggestions (revised 1992).

All sows were fed a standard gestation diet without fat before entering the farrowing facility at day 109 of gestation. Sows were randomly allotted to treatments and allowed to consume 4 lb of the respective experimental treatment from day 109 of gestation until farrowing. Treatments were replicated four times in each farrowing room. Farrowing crates were equipped with a drip cooling system activated when the ambient temperature reached 80°F. All sows were allowed *ad libitum* access to feed and water during the lactation period. Sows were weighed at day 109 of gestation, 24 hours after parturition, and at weaning. Pigs were processed within 24 hours of birth and cross-fostered if necessary within one day of birth irrespective of treatment. Sow feed intake was monitored weekly for the 28-day lactation period.

Results and Discussion

There was a trend ($P < .10$) for daily feed intake to decrease as energy density of the diet increased (Table 2). Sows that consumed the 4% tallow diet consumed 7.5% less feed than sows that consumed diet with no added fat. No differences ($P \geq .50$) were observed between treatments for daily ME or lysine intake. For the 28-day period, sows consumed 18.6 Mcal ME and 47 grams of lysine daily.

Production criteria (Table 3) were not affected ($P > .15$) by adding tallow to the diet. Sows lost an average of only 4.6 lb during lactation. Production criteria and pig survival observed in this study were good. Averaged across the three treatment groups, sows weaned 8.8 pigs with a total weight of 142 lb. After day 3 postfarrowing, pig survival was 96.6%.

Results from this experiment do not support an advantage to incorporating 2 to 4% of fat to lactation diets for primiparous sows. However, other advantages such as dust reduction and odor control may warrant low-level additions of fat. Also, fat additions may be justified during chronic periods of elevated environmental temperatures that reduce feed intake. For the feed intakes observed in this study, it seems that sows maintained a constant energy intake as dietary energy density increased by reducing daily feed consumption. Therefore, care should be taken when formulating diets with added fat to ensure that the intake of key nutrients (e.g., lysine) is maintained.

Table 2. Daily feed, metabolizable energy, and lysine intakes of lactating sows fed diets containing either 0, 2, or 4% added tallow[a]

Item	Dietary tallow, %				
	0	2	4	SEM[b]	P <
Number of sows	42	40	40	—	—
Daily feed intake, lb	13.08	12.70	12.10	.67	.07
Daily ME intake, Mcal	18.7	18.7	18.3	.38	.60
Daily lysine intake, g	47.5	47.2	46.2	.04	.50

[a]Twenty-eight day lactation
[b]Standard error of the mean

Table 3.Litter performance of pigs nursing sows fed diets containing 0, 2, or 4% added tallow[a]

Item	Dietary tallow, %				
	0	2	4	SEM[b]	P <
Number of sows	42	40	40	—	—
Pre-farrowing wt., lb	405.2	405.5	403.0	2.83	.95
Post-farrowing wt., lb	371.2	367.3	370.3	2.74	.75
Weaning wt., lb (sow)	365.7	364.8	364.6	3.01	.99
Total pigs born[c]	11.1	10.3	10.2	.80	.19
Pigs nursed[d]	9.1	9.2	9.1	.47	.75
Pigs weaned	8.8	8.9	8.7	.52	.64
Birth wt. of pigs weaned, lb	27.8	28.6	27.2	1.07	.44
Weaning wt., lb (litter)	140.7	144.4	141.0	2.31	.39
Pig survival, %	97.1	96.7	96.1	1.32	.54

[a]Twenty-eight day lactation
[b]Standard error of the mean
[c]Includes stillborns, but not mummified pigs
[d]Includes all pigs nursed from day 3 to day 28
[e]Calculated from day 3 to day 28 of lactation

Conclusions

Although previous research has documented a positive response of lactating sows to fat additions of 8 to 10%, results from this experiment documenting performance criteria from sows consuming up to 4% tallow, showed no production response. Moreover, sows fed diets with added fat usually consume less feed. Thus, it may be necessary to increase the density of other nutrients in the diet to maintain an adequate daily intake of those nutrients.

[1]Phillip S. Miller is an Assistant Professor, Austin J. Lewis is a Professor, and Cynthia K. Wolverton is a Research Technologist in the Department of Animal Science at the University of Nebraska-Lincoln.

Plasma Urea Concentration as an Index of the Protein Requirements of Growing-Finishing Pigs

Hsin-Yi Chen
Phillip S. Miller
Austin J. Lewis[1]

A major challenge to improving swine feeding programs is adopting new techniques to improve the accuracy of determining protein requirements.

This is important for a variety reasons: First, there are currently many different commercial populations of pigs (commonly called genotypes) and these different populations may have different protein requirements because of their different lean growth potentials. Secondly, dietary protein levels should be carefully tailored to pigs' lean growth potential because both inadequate and excessive feeding of protein can reduce performance and increase production costs. Finally, it is too expensive and time consuming to perform traditional feeding and carcass analysis experiments for every possible population. Therefore, a simple procedure to identify protein requirements of growing-finishing pigs is needed.

This study investigated the use plasma urea concentrations as an index of the protein requirements of different pig populations. Plasma urea was chosen because urea is produced when the amino acids that make up proteins are broken down. High plasma urea concentrations may indicate that too much protein is being fed.

Procedures

Our experiments included two pig populations that we expected to have different protein requirements: Nebraska Gene Pool pigs (from the University herd) and modern Hampshire pigs (from a Nebraska SPF breeder).

The Gene Pool population is a 14-breed composite, formed from 1962 to 1965 and then closed to outside breed introductions. Since 1967 it has been selected only for reproductive traits. Therefore, growth and carcass characteristics of the Gene Pool population are typical of pigs 30 years ago. The Hampshire pigs have been selected for lean growth traits and represent pigs of a fairly high lean growth type.

Seventy-two gilts were allotted in a randomized complete block experiment with a 2 × 6 factorial arrangement of treatments. There were the two populations of pigs and six protein levels (10, 13, 16, 19, 22, and 25% crude protein [CP]). Diets (Table 1) were corn-soybean meal-based and were fortified to meet or exceed the National Research Council requirements of 44- to 110-lb pigs. The range of CP levels was obtained by changing the ratio of corn and soybean meal.

Pigs were housed individually and had *ad libitum* access to feed and water throughout the experiment. The initial weight was 63 lb and the final weight was 250 lb. The test period lasted 14 wk for Hampshire pigs and 16 wk for Gene Pool pigs.

Our first goal was to determine whether pigs of the two populations have different protein requirements. Significant differences between the two populations were found for growth performance, carcass traits, and the rates at which tissue was deposited. Population × protein level interaction was significant for protein accretion. Hampshire pigs had a greater magnitude of response to increased dietary protein concentration than did Gene Pool pigs (details of this part of the research were described in the 1994 Nebraska Swine Report).

Each week during the experiment blood samples were collected from the pigs and the plasma was analyzed for urea. Plots of urea concentrations against time were examined to see whether differences between the two populations of pigs and differences during the time course of the experiment could be identified.

Table 1. Composition of diets[a]

	Dietary protein concentration, %					
Item	10	13	16	19	22	25
Ingredient, %						
Corn	92.10	84.00	75.65	67.25	59.00	50.80
Soybean meal, 44% CP	5.00	13.25	21.75	30.25	38.65	47.00
Dicalcium phosphate	1.40	1.25	1.05	.90	.70	.55
Limestone	.40	.40	.45	.50	.55	.55
Salt	.30	.30	.30	.30	.30	.30
Trace mineral premix	.10	.10	.10	.10	.10	.10
Vitamin premix	.70	.70	.70	.70	.70	.70
Nutrient composition[b]						
Crude protein, %	9.75	12.53	15.53	18.61	21.33	24.29
Lysine, %	.36	.55	.75	.95	1.16	1.35
Calcium, %	.64	.62	.62	.63	.64	.62
Phosphorus, %	.56	.53	.53	.53	.51	.51
Metabolizable energy, kcal/lb[c]	1,502	1,496	1,491	1,485	1,480	1,475

[a] As-fed basis.
[b] Analyzed composition.
[c] Calculated.

Results

Plasma urea analyses results are illustrated in Figure 1. In the Gene Pool pigs, plasma urea concentrations of pigs fed the two lowest levels of protein (10 and 13%) remained low and relatively constant for the first half of the experiment. However, urea concentrations of pigs fed diets with ≥ 16% CP increased almost immediately and remained elevated throughout the experiment. For pigs in these groups (16, 19, 22, and 25% CP), plasma urea concentration increased with increases in dietary protein level.

These findings are interpreted to mean that during the first half of the experiment the protein requirements of Gene Pool pigs were between 13 and 16% CP. During the second half of the experiment, urea concentrations of pigs fed 13% CP steadily deviated from those of pigs fed 10% CP. We interpret this to mean that as the pigs gained weight their protein requirements (as a percentage of the diet) decreased and that during the final phase of the experiment the protein requirement of Gene Pool pigs was between 10 and 13% CP.

For Hampshire pigs, urea concentrations of pigs fed diets with 10, 13, 16, and 19% CP were similar for the first 3 weeks of the experiment, indicating that during this period the requirement was ≥ 19% CP. From 3 to 12 weeks the requirement seemed to be between 16 and 19% CP. After 12 weeks of the experiment, urea concentrations of pigs fed 16% CP deviated from those fed 10 or 13% CP. We interpret these findings to mean that Hampshire pigs required 19% CP from wk 0 to 3 (66 to 100 lb body weight), 16% CP from wk 3 to 12 (100 to 220 lb body weight), and 13% CP after wk 12 (220 to 250 lb body weight).

Thus, the protein requirements determined using plasma urea concentration indicated differences between the two populations. The differences were similar to the results based on growth performance and carcass traits. However, the technique of plasma urea concentration seemed to reflect the protein requirements of the two populations of pigs more precisely and dynamically than growth performance and carcass characteristics. Although more work will be needed to adapt this technique for practical on-farm use, the plasma urea technique may provide a valuable index to help identify whether the protein needs of pigs are being met or whether protein is being overfed.

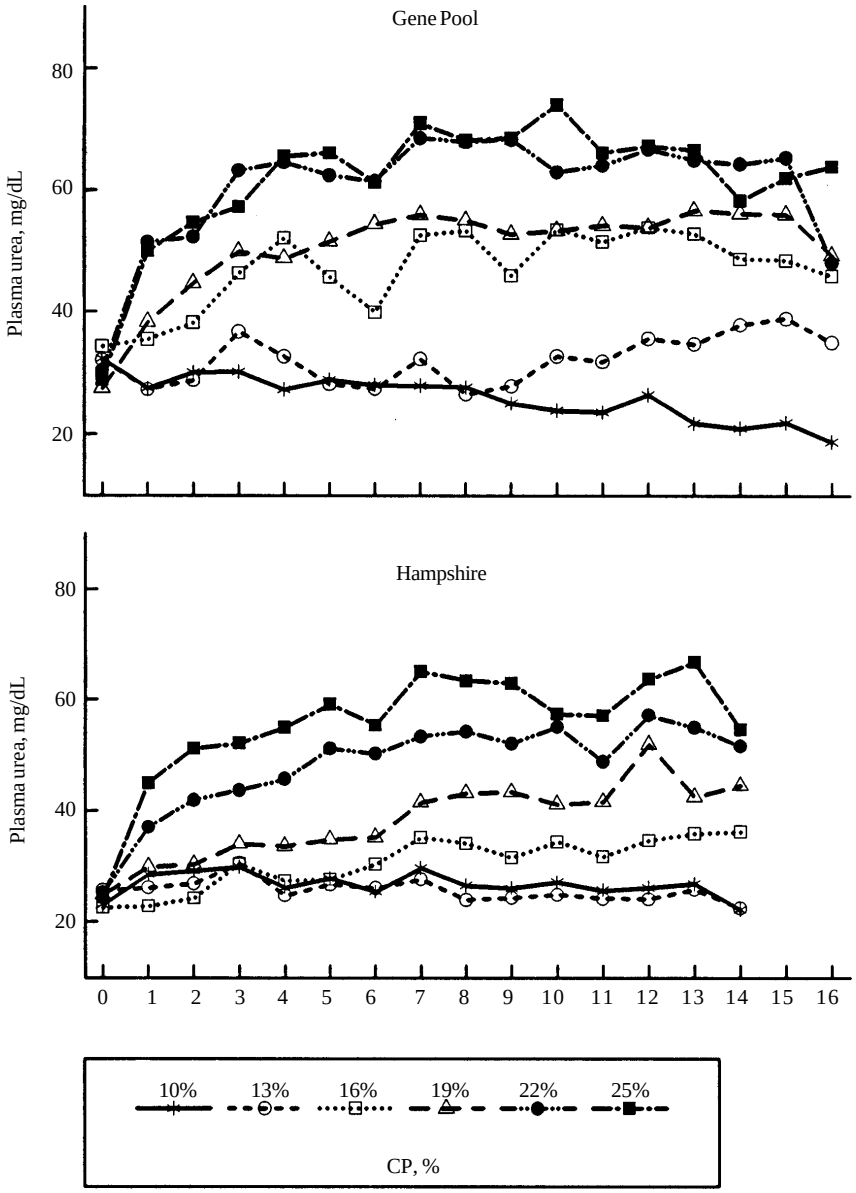

Figure 1. Plasma urea concentrations of two populations of pigs.

Conclusions

When conditions are properly controlled, the plasma urea concentration of growing-finishing pigs is a valuable index of whether the dietary protein content is deficient, adequate, or excessive. When adapted for practical on-farm use, this method could provide a valuable tool for adjusting dietary protein levels for differing populations that vary in lean gain potential. Additional research is still required to evaluate the effects of factors such as sex, protein quality, use of crystalline amino acids, and energy intake on plasma urea concentration.

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Nursery and Growing-Finishing Space Interactions

Mike Brumm
Jim Dahlquist[1]

The reductions in feed intake and daily gain as space is restricted have been clearly documented for pigs in nursery and growing-finishing facilities. The general management recommendation has been to provide sufficient space for maximum performance (daily gain) in nurseries while often restricting space in growing-finishing facilities for best economic performance. However, as female reproductive performance within a herd increases, there often is more crowding of weaned pigs in the nursery. The effect of this crowding on subsequent performance has not been determined.

This experiment was designed to investigate the possible interaction of nursery space allocation and growing-finishing space allocation on performance from weaning to slaughter.

Experimental Procedure

In each of two trials, 144 crossbred weaned pigs (24 $\pm$ 3 d of age) were purchased from a single source and transported 12 miles to the University of Nebraska Northeast Research and Extension Center swine unit within 2 hours of weaning.

Pigs were eartagged, weighed, blocked by weight into two groups. Equal number of barrows and gilts were randomly assigned within weight group to experimental treatments.

In the nursery phase, pigs were housed either 12 (UN) or 18 (CN) pigs per 4 ft $\times$ 8 ft deck (2.7 vs 1.8 ft^2/pig). Each deck had two nipple drinkers. There was one feeder space for every two pigs in both treatments. For the first week after weaning, air temperature in the pig zone was maintained at 86° F. Beginning one week after weaning, thermostat settings were reduced 3.6° F per week. From 7:00 p.m. to 7:00 a.m., thermostat settings were reduced an additional 10 to 11° F.

After the five-week nursery period, all pigs were moved to a partially slatted, fan ventilated growing-finishing facility. Within nursery space treatments, pigs were blocked by weight and sex into three groups and were randomly assigned within weight group to the growing-finishing space treatments of either 10 (UGF) or 14 (CGF) pigs per pen (8.4 vs 6.1 ft^2/pig). Each growing-finishing pen had one nipple drinker and three feeder holes. Sprinklers were provided for summer heat relief and pen sizes were not adjusted when a pig died or was removed from the experiment for unsatisfactory performance.

On the week individual pigs weighed 230 pounds or greater, they were slaughtered at SiouxPreme Packing Co. in Sioux Center, Iowa. Total Body Electrical Conductivity was used on individually identified pigs to provide an estimate of carcass lean.

Table 1. Effect of nursery space allocation on weaned pig performance (least squares means).

	Treatment[a]	
	CN	UN
No. pens	8	12
No. pigs	144	144
Pig weight, lb		
Initial	14.6	14.7
35 d[b]	42.7	46.1
Average daily gain, lb[b]	.80	.90
Average daily feed, lb[b]	1.34	1.51
Feed:gain	1.67	1.67
Pigs dead/removed, no.	0	1

[a]CN = 18 pigs/pen (1.8 ft^2/pig); UN = 12 pigs/pen (2.7 ft^2/pig)
[b]Means differ $P < .001$.

At weaning, all pigs were offered a commercial, pelleted starter (1.4% lysine) until the week the individual pen weight was 23 lb or greater. They were then offered a 1.15% lysine diet formulated with corn and soybean meal and 3% added fat for the duration of the nursery phase of the experiment.

During the growing-finishing phase, all corn-soy diets contained 3% added fat and were formulated to contain 0.9% lysine to 90 lb live weight, 0.8% lysine from 90 to 180 lb and 0.7% lysine from 180 lb to slaughter.

Results

Table 1 presents the results of the nursery phase of the experiment. There were no trial by treatment or weaning

Table 2. Effect of nursery and grow-finish space allocations on grow-finish performance.

Item	Treatment[a]				Probability levels for contrasts among means		
	CN		UN				
	UGF	CGF	UGF	CGF	CNUGF vs CNCGF	UNUGF vs UNCGF	CNCGF vs UNCGF
	(1)	(2)	(3)	(4)	(1 vs 2)	(3 vs 4)	(2 vs 4)
No. pens	6	6	6	6			
No. pigs	60	84	60	83			
Pig weight, lb							
Final	242.3	241.3	244.9	237.1	NS[c]	<.0005	<.05
Average daily gain, lb	1.87	1.80	1.91	1.72	.075	<.0001	<.05
Average daily feed, lb	5.70	5.57	5.86	5.42	NS	<.005	NS
Feed:gain	3.05	3.10	3.07	3.15	NS	NS	NS
Carcass lean, %[b]	46.3	47.7	46.3	47.8	< .01	<.005	NS
Lean gain, lb/d	.66	.66	.67	.63	NS	<.05	NS
Pigs dead/removed, no.	1	3	3	3			

[a]CN = 18 pigs/nursery pen (1.8 ft^2 /pig); UN = 12 pigs/nursery pen (2.7 ft^2/pig); UGF = 10 pigs/GF pen (8.4 ft^2/pig); CGF = 14 pigs/GF pen (6.1 ft^2/pig).
[b]Containing 5% fat.
[c]Not significantly different ($P > .1$).

weight block by treatment interactions so the results are presented for the main effect of space treatment. Similar to previously reported results from numerous researchers, putting more pigs in a nursery pen (less space per pig and more pigs per social group) resulted in reduced feed intake, reduced daily gain, and a 3.4 lb lighter pig from the nursery at 35 days postweaning.

Table 2 presents the results of the growing-finishing phase of the experiment. Similar to the nursery phase, there were no trial by treatment interactions so only main effects are presented. When pigs were crowded in the nursery (CN), there was no significant effect of crowding in the growing-finishing phase (CGF vs UGF) on average daily feed (5.57 vs 5.70 lb/d) or feed conversion (3.10 vs 3.05). However, carcass % lean was greater in the crowded pigs (47.7% vs 46.3%) and daily gain was less (1.80 vs 1.87 lb/d). Therefore, there was no difference in the rate of lean gain (.66 vs .66 lb/d).

When uncrowded nursery pigs (UN) were moved to the growing-finishing facility, crowding (UNCGF) significantly reduced average daily gain (1.72 vs 1.91 lb/d), daily feed intake (5.42 vs 5.86 lb/d), carcass % lean (46.3% vs 47.8%) and the rate of lean gain (.63 vs .67 lb/d) compared to uncrowded pigs (UNUGF).

Based on these results, we conclude that space (group size and pen space) allocation in the nursery phase affects the response of growing-finishing pigs to space restrictions. Especially evident is the depression in growing-finishing performance reported for uncrowded nursery pigs that were crowded in growing-finishing facilities compared to the performance of crowded nursery pigs that were subsequently crowded in growing-finishing facilities.

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