Effects of increasing dietary niacin on growth performance and meat quality in finishing pigs reared in two different environments[1,2]

D. E. Real, J. L. Nelssen, J. A. Unruh, M. D. Tokach, R. D. Goodband[3], S. S. Dritz[4], J. M. DeRouchey, and E. Alonso†

*Department of Animal Sciences and Industry, Kansas State University, Manhattan, 66506-0201, and †Lonza, Inc., Fair Lawn, NJ 07410

ABSTRACT: We conducted two experiments to determine the effects of added dietary niacin on growth performance and meat quality in finishing pigs. Pigs were blocked by weight and assigned to one of six dietary treatments in both experiments. Dietary treatments consisted of a corn–soybean meal-based control diet (no added niacin) or the control diet with 13, 28, 55, 110, or 550 mg/kg of added niacin. In Exp. 1, pigs were housed at the Kansas State University research farm with two pigs per pen (six pens per treatment per sex). In Exp. 2, pigs were housed with 26 pigs per pen (four pens per treatment per sex) in a commercial research barn. In Exp. 1, 144 pigs (initially 51.2 kg) were fed diets in two phases (d 0 to 25 and 25 to 62) that were formulated to 1.00 and 0.75% lysine, respectively. In Exp. 2, 1,248 pigs (initially 35.9 kg) were fed diets in four phases (d 0 to 28, 29 to 56, 57 to 84, and 85 to 117), with corresponding total lysine concentrations of 1.25, 1.10, 0.90, and 0.65% lysine, respectively. Added fat (6.0%) was included in the first three phases. In Exp. 1, average daily feed intake tended (quadratic, $P < 0.07$) to increase then return to values similar to control pigs as dietary niacin increased. Longissimus muscle (LM) 24-h pH (longissimus of pigs fed added niacin) tended to increase (control vs niacin, $P < 0.06$) for pigs fed added niacin. In the commercial facility (Exp. 2), increasing added niacin improved gain:feed (quadratic, $P < 0.01$) and subjective color score, and ultimate pH (linear, $P < 0.01$). Added niacin also decreased (linear, $P < 0.04$) carcass shrink, L* values, and drip loss percentage. Results from these two studies show that 13 to 55 mg/kg added dietary niacin can be fed to pigs in a commercial environment to improve gain:feed. It also appears that pork quality, as measured by drip loss, pH, and color, may be improved by higher concentrations of added dietary niacin.

Key Words: Finishing, Growth, Meat Quality, Nicotinic Acid, Performance, Pigs

 J. Anim. Sci. 2002. 80:3203–3210

Introduction

Niacin has long been accepted as an essential vitamin in swine diets; however, the optimal inclusion rate for finishing pigs has been debated. The NRC (1998) suggests that growing and finishing pigs require 10 mg of niacin per kilogram of feed up to 50 kg BW and only 7 mg/kg thereafter. According to a survey of feed manufacturers and university requirement estimates (BASF, 1997), the average inclusion rate of niacin was 23 mg/kg in finishing diets. The average of the upper 25% of niacin inclusion rates was 35 mg/kg, and the average of the lower 25% inclusion rates was 13 mg/kg.

Niacin requirement estimates can be influenced by several factors, including vitamin concentrations and availability in ingredients (Yen et al., 1977) and level of metabolic precursors in the diet (Firth and Johnson, 1956). There have been several studies investigating niacin requirements in growing and finishing pigs (Harmon et al., 1969; Yen et al., 1978). Ivers and Veum (1993) reported no improvements in growth performance when supplementing low-protein diets with 81 mg/kg of crystalline niacin. Recently, Piva (1995) observed improvements in reflectance values of the semimembranosus muscle when feeding 75 mg/kg of niacin to finishing pigs 7 d prior to harvest. However, there were no reports on longissimus muscle (**LM**) quality. Therefore, due to the wide range in supplementation rates and the lack of information concerning the influence of niacin on meat

[1]Contribution no. 02-171-J from the KS Agric. Exp. Stn., Manhattan 66506.

[2]We would like to thank Lonza, Inc., Fair Lawn, NJ, for partial financial support as well as providing the niacin used in these experiments. We would also like to thank Global Ventures, Inc., Pipestone, MN, for use of their facilities and animals used in Exp. 2.

[3]Correspondence: Phone: (785) 532-1228; fax: (785) 532-7059; E-mail: Goodband@ksu.edu.

[4]Contact address: Food Animal Health and Management Center, College of Veterinary Medicine, Kansas State University.

Received February 7, 2002.

Accepted August 8, 2002.

quality, we conducted this study to determine the effects of added niacin in finishing diets on pig performance and meat quality characteristics.

Materials and Methods

General. The experimental protocols used in these experiments were approved by the Kansas State University Animal Care and Use Committee. We conducted the first experiment in a university research facility to study the effects of additional dietary niacin on growth performance, carcass characteristics, and meat quality. A second study was conducted to evaluate niacin supplementation on pigs reared in a commercial finishing environment. Niacin from niacinamide (Lonza, Inc., Fair Lawn, NJ) was added to the basal diets to achieve the treatment levels of 13, 28, 55, 110, and 550 mg of added niacin per kilogram of feed. The basal diets from both experiments were analyzed in duplicate for total niacin content (University of Missouri Experiment Station Chemical Laboratories, Columbia).

Experiment 1. A total of 144 pigs, of which 72 were barrows and 72 were gilts (PIC C22 × Line 326; initially 51.2 kg) were housed in an environmentally controlled finishing facility with totally slatted concrete floors. Each pen (1.5 m^2) contained two pigs, a nipple waterer, and a one-hole stainless steel self-feeder to provide ad libitum access to feed and water. Pigs were randomly allotted and blocked by initial weight and sex in a randomized complete block design. There were six replicate pens per treatment per sex.

Diets (Table 1) were fed in two phases. The phase I diet was fed from d 0 to 25 and formulated to contain 1.0% lysine, and the phase II diet was fed from d 25 to 62 and formulated to contain 0.75% lysine. The diets were corn–soybean meal-based, contained no added fat, and were fed in meal form. Pigs and feeders were weighed every 2 wk to determine ADG, ADFI, and gain:feed ratio.

One pig (closest to 109 kg) from each pen was slaughtered at the Kansas State University Meats Laboratory when the mean weight of pigs within a block was 109 kg. An entire block was removed from the experiment at the same time. The evening before harvest, at approximately 1600, pigs were weighed and tattooed. Pigs were then loaded on a stock trailer and transported approximately 5 km to the Kansas State University Meats Laboratory. Pigs were then housed in the USDA inspection pens overnight and allowed ad libitum access to only water. At 0600, the first pig was electrically stunned and bled using standard industry procedures approved by the Kansas State University Animal Care and Use Committee. One pig was stunned and bled every 6 to 7 min. At 45 min and 1-h postmortem, longissimus muscle (LM) pH and temperature were recorded at the 10th rib using an Accumet pH meter (Hudson, MA) and a Corning spear gel combo probe (Acton, MA). Hot carcass weight was recorded to determine dressing percentage.

After chilling at 1°C for at least 24 h, carcasses were reweighed and measured for carcass length and backfat thickness opposite the first rib, last rib, and last lumbar vertebra at the midline to calculate average backfat. Carcasses were then ribbed, and one chop was removed (10th rib chop) and allowed to bloom for 30 min. Subjective color, marbling, and firmness scores on the LM were evaluated on the 10th/11th rib surface according to NPPC (2000) guidelines.

Immediately thereafter, color spectrophotometry measurements (L*, a*, and b*; CIE, 1976) of the LM were measured in duplicate using a Hunter Lab Miniscan XE model 45/O-L with a C illuminant with a 10° observer (Hunter Associates Laboratory, Reston, VA). The L* value represents the lightness of the sample. Longissimus muscles with a higher L* value would be lighter in color. The a* values are chromatic coordinates representing a change from green to red color. A higher a* value indicates a sample with more red color. The b* values are also chromatic coordinates, representing a change in color from blue to yellow. The higher b* value, the more yellow the sample is in color. Reflectance values were also measured and are presented as a ratio of the percent reflectance of 630 wavelength to 580, which represent the oxymyoglobin to metmyoglobin ratio. Longissimus muscle area at the 10th rib was traced and fat depth opposite the 10th rib was measured. These measurements were used to calculate a fat-free lean index according to NPPC (2000) guidelines. Chops were then dissected, and a 25-mm^3 sample was taken to determine drip loss using the method described by NPPC (2000). An

Table 1. Basal diet compositions (Exp. 1)

	Phases	
Item	d 0 to 25	d 25 to 62
Ingredient, %		
Corn	74.31	83.53
Soybean meal (46.5%)	22.79	13.72
Limestone	0.90	0.85
Monocalcium P (21% P)	0.90	0.80
Salt	0.35	0.35
Cornstarch[a]	0.35	0.35
Vitamin premix[b]	0.15	0.15
Lysine HCl	0.15	0.15
Trace mineral premix[c]	0.10	0.10
Chemical composition		
Lysine, %[d]	1.00	0.75
Tryptophan, %[d]	0.19	0.14
Calcium, %[d]	0.61	0.54
Phosphorus, %[d]	0.56	0.50
Total niacin, mg/kg[e]	26.8	25.0
Available niacin, mg/kg[f]	7.75	4.66

[a]Cornstarch was replaced by niacin from nicotinic acid (Lonza, Fairlawn, NJ) to provide 13, 28, 55, 110, and 550 mg/kg.
[b]Provided 6,600 USP of vitamin A, 990 USP of vitamin D_3, 26 IU of vitamin E, 2.64 mg of B_{12}, 6 mg of riboflavin, and 20 mg of pantothenic acid per kilogram of diet.
[c]Provided 165 mg of zinc, 165 mg of iron, 40 mg of manganese, 17 mg of copper, 0.30 mg of iodine, 0.30 mg of selenium per kilogram of diet.
[d]Calculated content (NRC, 1998).
[e]Analyzed content.
[f]Calculated by subtracting niacin in corn (NRC, 1998) from total analyzed content.

Table 2. Basal diet compositions (Exp. 2)

Item	Phases			
	d 0 to 28	d 28 to 56	d 56 to 84	d 84 to 117
Ingredient, %				
Corn	58.61	64.26	71.97	87.76
Soybean meal, 46.5%	32.44	26.99	19.70	10.06
Choice white grease	6.00	6.00	6.00	0.00
Monocalcium phosphate, 21% P	1.25	1.10	0.70	0.60
Limestone	0.90	0.90	0.90	0.85
Salt	0.35	0.35	0.35	0.35
Vitamin premix[a]	0.15	0.15	0.13	0.13
Trace mineral premix[b]	0.15	0.10	0.10	0.10
Lysine HCl	0.15	0.15	0.15	0.15
Chemical composition				
Lysine, %[c]	1.25	1.10	0.85	0.60
Tryptophan, %[c]	0.25	0.21	0.16	0.11
Calcium, %[c]	0.70	0.66	0.56	0.49
Phosphorus, %[c]	0.65	0.60	0.48	0.44
Total niacin, mg/kg[d]	24.9	24.8	24.5	24.6
Available niacin, mg/kg[e]	11.0	9.2	6.7	3.4

[a]Provided dietary treatments of 0, 13, 28, 55, 110, or 550 mg/kg of niacin. Also provided 6,600 USP of vitamin A, 990 USP of vitamin D_3, 26 IU of vitamin E, 2.64 mg of B_{12}, 6 mg of riboflavin, and 20 mg of pantothenic acid per kilogram of diet from d 0 to 56, and 83% of these levels from d 56 to 117.

[b]Provided 165 mg of zinc, 165 mg of iron, 40 mg of manganese, 17 mg of copper, 0.30 mg of iodine, 0.30 mg of selenium per kilogram of diet from d 0 to 28, and 67% of these levels from d 28 to 117.

[c]Calculated content (NRC, 1998).

[d]Analyzed content.

[e]Calculated by subtracting niacin in corn (NRC, 1998) from total analyzed content.

additional 0.5-g sample was taken to determine water-holding capacity using the method described by Grau and Hamm (1956). Finally, ultimate pH and temperature of the LM were measured at the 11th rib.

Experiment 2. A total of 624 barrows and 624 gilts (PIC C22 × 327; initially 36.2 kg) were used in this study with four pens per treatment per sex. Pigs were blocked by initial weight and sex and were randomly allotted to one of six dietary treatments. Pigs were housed with 26 pigs per 3.2 × 5.7 m pen (provided 0.69 m^2 per pig) in a commercial research facility in southwestern Minnesota. Each of the pens was equipped with an eight-hole stainless steel dry self-feeder and one-cup waterer to provide ad libitum access to feed and water. The deep pit, double curtain sided barn had a totally concrete slatted floor with 48 pens.

Pigs were fed diets in four phases (Table 2). From d 0 to 28, pigs were fed a diet formulated to contain 1.25% lysine and 6% added fat. From d 28 to 56, pigs were fed a 1.10% lysine diet with 6% fat. A 0.90% lysine diet with 6% fat was fed from d 56 to 84. The final diet was fed from d 84 to 117 and was formulated to 0.65% lysine with no added fat. All diets were corn–soybean meal-based and contained 0.15% L-lysine HCl. The same concentrations of added niacin were used in Exp. 2 as described for Exp. 1.

On d 113, one pig per pen from the two heaviest blocks was randomly selected, tattooed, and transported to the Kansas State University Meat Laboratory for meat quality measurements. Then, one pig/pen from the two lightest blocks of pigs was selected similarly on d 117. On that day, the remaining pigs in the barn were tattooed and transported to commercial slaughter facilities for harvest.

Once pigs were identified, at approximately 1100, 24 pigs on both d 113 and 117 were loaded on to a stock trailer (2.74 × 7.32 m) and transported for approximately 8 h to the Kansas State University Meats Laboratory. Pigs were then housed in the USDA inspection pens on location and allowed ad libitum access to water only. After a period of approximately 19 h of fasting, pigs were electrically stunned, and harvested as previously described in Exp. 1. Carcass and meat quality characteristics were measured similar to Exp. 1 with two adjustments. In Exp. 2, the LM was also evaluated for wetness according to NPPC guidelines (2000), and pH was measured with an Accumet pH meter and a Sentron Red-Line Lance FET probe (St. Hingham, MA). For the remaining pigs sent to a commercial packing plant (Swift & Co., Worthington, MN), fat and loin depth were measured with an optical probe and used to calculate a percentage fat-free lean value.

Statistical Analysis. Data from the two experiments were analyzed separately using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a split-plot design with dietary niacin as whole plot and sex as the subplot. Pen served as the experimental unit for all statistical analyses. The model included contrasts for unequally spaced linear and quadratic effects of increasing dietary niacin for all six treatments, as well as linear and quadratic contrasts for all treatments excluding the 550-mg/kg treatment (0 to 110 mg/kg niacin). We chose this analysis to more accurately discern treatment differences due to the large amount of emphasis that would have

Table 3. Effects of added dietary niacin on growth performance of growing-finishing pigs (Exp 1.)[a]

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[b]	Linear	Quadratic
d 0 to 62										
ADG, g	1,068	1,035	1,048	1,089	1,081	1,050	17.0	0.71	0.66	0.09
ADFI, g[c]	2,848	2,934	2,943	2,998	3,048	2,844	66.2	0.08	0.18	0.007
Gain:feed	0.37	0.35	0.35	0.36	0.35	0.36	0.009	0.11	0.33	0.29
Initial weight, kg	51.3	51.2	51.2	51.2	51.2	51.2	0.038	0.02	0.42	0.45
Final weight, kg[d]	116.8	114.6	115.8	118.4	117.9	115.5	1.118	0.77	0.54	0.06

[a]Values represent the mean of eight observations per treatment, with four observations of barrows and four of gilts. No treatment × sex interactions ($P > 0.05$) were observed.
[b]Control vs added niacin.
[c]110 mg/kg of niacin vs 550 mg/kg of niacin ($P < 0.05$); linear ($P < 0.01$) when comparing 0 through 110 mg/kg of niacin.
[d]Linear ($P < 0.09$) when comparing from 0 to 110 mg/kg of niacin.

been placed on the 550-mg/kg treatment in the statistical analysis of all treatments. Also, contrasts for the control treatment vs added niacin treatments, control vs 550 mg/kg, and 110 mg/kg vs 550 mg/kg were analyzed to more appropriately discern treatment differences given the treatment structure.

Results

Experiment 1. There were no ($P > 0.05$) treatment × sex interactions for overall growth performance. Barrows grew faster (1,104 vs 1,019 g/d), consumed more feed (2,497 vs 2,170 g/d), were less efficient (0.44 vs 0.47), and were heavier (119.4 vs 113.6 kg) than gilts ($P < 0.03$), as was expected. Overall, increasing dietary niacin tended to increase (quadratic, $P < 0.09$) ADG, with ADG increasing up to 55 mg/kg then returning to levels similar to control pigs (Table 3). Increasing niacin increased then decreased (quadratic, $P < 0.007$) ADFI. This quadratic response appeared to be because of decreased ADFI of pigs fed the 550 mg/kg niacin treatment. When evaluating linear and quadratic polynomials excluding the 550 mg/kg treatment, increasing added niacin increased (linear, $P < 0.01$) ADFI up to 110 mg/kg. Feed efficiency was unaffected by increasing added dietary niacin. At the end of the experiment, final weight of pigs followed the same pattern as ADG, tending to increase (quadratic, $P < 0.06$) up to 55 mg/kg, then decreasing. When comparing treatments from 0 to 110 mg/kg of niacin, the response tended to be linear ($P < 0.09$).

Carcasses from gilts had less backfat depth at the 10th rib (19.4 vs 28 mm), shorter carcasses (81.0 vs 83.8 cm), increased cooler shrink (1.78 vs 0.95%), larger loin eye areas (45.5 vs 38.1 mm^2), and increased fat-free lean indexes (53.37 vs 47.63%) than carcasses from barrows ($P < 0.02$). Increasing dietary niacin decreased (linear, $P < 0.04$) hot carcass weight and cold carcass weight. However, this effect was mainly due to the decrease in weight when pigs were fed 550 mg/kg niacin (Table 4), because there were no differences ($P > 0.50$) in hot or cold carcass weights among pigs fed 0 to 110 mg/kg of added niacin. Increasing added dietary up to 550 ppm had no effect ($P > 0.10$) on dressing percentage, backfat depth, carcass length, or loin eye area.

Increasing added niacin had no affect ($P > 0.10$) on subjective color (Table 5). However, the mean marbling score of pigs fed added niacin was greater ($P < 0.02$) than those fed the control diet. There were no differences ($P > 0.10$) in drip loss, water-holding capacity, or instrumental color values. Pigs fed 550 mg/kg niacin had cooler temperatures ($P < 0.02$) 45 min postmortem than those not fed additional dietary niacin.

Experiment 2. Barrows grew faster (790 vs 736 g/d; $P < 0.001$), tended to consume more feed (2,247 vs 1,977 g/d, $P < 0.07$) and weighed more than gilts (130.2 vs 123.3 kg, $P > 0.001$). Overall, increasing dietary niacin tended to decrease (linear, $P < 0.06$) ADG, although when comparing 0 to 110 mg/kg niacin treatments, niacin tended to increase (quadratic, $P < 0.06$) ADG up to 13 mg/kg and then returned to control levels for pigs fed 110 or 550 ppm (Table 6). Increasing dietary niacin decreased (quadratic, $P < 0.01$) ADFI, and as a result, feed efficiency improved (quadratic, $P < 0.01$) with increasing dietary niacin. There were no differences ($P > 0.17$) in final weight among treatments.

For pigs harvested at the Kansas State University Meat Laboratory, carcasses from barrows were heavier (88.8 vs 85.3 kg; $P < 0.01$), had less cooler shrink (0.61 vs 1.51%, $P < 0.04$)), lower fat-free lean indexes (54.88 vs 51.31%, $P < 0.01$), greater 10th rib fat depth (21.9 vs 16.6 mm, $P < 0.03$), and tended to have smaller loin eye areas (41.5 vs 46.9 mm^2, $P < 0.01$) than carcasses from gilts. There was a sex × treatment interaction ($P < 0.04$) for hot carcass weight and cold carcass weight for pigs harvested at the Kansas State University Meat Laboratory (Table 7). In both of these criteria, increasing added dietary niacin decreased weights of barrows (89.2, 91.8, 90.9, 89.2, 85.4, and 86.3 kg hot weight) while increasing weights of gilts (81.9, 84.9, 84.7, 84.0, 87.5, and 89.0 kg hot weight). For pigs harvested at commercial slaughter facilities, there was also a sex × treatment interaction ($P < 0.01$) for loin depth at the 10th rib. Increasing added dietary niacin increased and then decreased loin depth of barrows (58.2, 59.5, 61.2, 60.6, 59.1, and 57.3) while

Table 4. Effects of added dietary niacin on carcass characteristics of grow-finish pigs (Exp. 1)[a]

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[b]	Linear	Quadratic
Hot weight, kg	86.5	86.5	85.9	88.9	86.0	84.3	0.943	0.89	0.03	0.50
Dress, %	75.1	75.6	75.4	75.7	75.0	74.7	0.375	0.61	0.13	0.91
Cold weight, kg	85.2	85.3	84.6	87.7	84.9	83.3	0.932	0.99	0.04	0.43
Shrink, %	1.51	1.38	1.47	1.26	1.31	1.23	0.124	0.19	0.18	0.32
Fat-free lean, %[c]	49.95	51.33	51.35	50.02	49.62	50.74	0.744	0.42	0.91	0.23
Backfat, mm										
First rib[d]	41.4	39.0	39.5	43.1	40.9	38.6	1.706	0.49	0.29	0.42
Last rib[d]	27.9	29.8	28.1	30.9	28.6	28.4	1.277	0.35	0.70	0.65
Last lumbar[d]	22.0	20.7	18.3	21.7	21.3	18.3	1.355	0.17	0.11	0.59
Tenth rib[d]	24.3	22.7	22.8	25.6	24.5	22.6	1.181	0.60	0.38	0.22
Average[d]	30.4	29.8	28.6	31.9	30.2	28.4	1.106	0.58	0.18	0.42
Length, cm[d]	83.1	81.9	82.3	82.6	82.3	82.5	0.469	0.14	0.94	0.64
Loin eye, cm^{2}[de]	40.4	42.9	43.9	41.9	40.2	41.5	1.418	0.24	0.72	0.46

[a]Values represent the mean of eight observations per treatment (four barrows and four gilts).
[b]Control vs. added niacin; no treatment × sex interactions ($P > 0.16$).
[c]Quadratic ($P < 0.08$) when comparing 0 through 110 mg/kg of niacin.
[d]Hot weight as covariate (86.33).
[e]Quadratic ($P < 0.03$) when comparing 0 through 110 mg/kg of niacin.

decreasing and then increasing loin depth of gilts (59.7, 58.2, 58.9, 56.3, 60.4, and 60.2). There were no ($P > 0.12$) sex × treatment interactions for other carcass measurements. Increasing niacin decreased (control vs niacin, $P < 0.02$) cooler shrink of carcasses; however, there were no differences ($P > 0.10$) among treatments for hot carcass weight, cold carcass weight, dressing percentage, fat-free lean index, any fat depth measurements, carcass length, or loin eye area (Table 7).

Tenth rib LM of barrows had more (1.5 vs 1.1; $P < 0.02$) marbling, higher a* values (8.41 vs 7.35, $P < 0.05$), and a larger a*:b* ratio (0.63 vs 0.57, $P < 0.01$). Increasing added dietary niacin improved (linear, $P < 0.01$) subjective color scores, subjective wetness scores (linear, $P < 0.01$), and decreased (linear, $P < 0.04$) drip loss percentage of the LM (Table 8). Increasing dietary niacin also decreased (linear, $P < 0.001$) L* values, tended to decrease (linear, $P < 0.10$) a* values, and decreased (linear,

Table 5. Effects of added dietary niacin on longissimus (10th rib) quality of growing-finishing pigs (Exp. 1)[a]

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[b]	Linear	Quadratic
Color[c]	2.2	2.4	2.3	1.7	2.4	2.5	0.16	0.70	0.11	0.65
Marbling[de]	2.2	2.7	2.8	2.7	2.6	2.6	0.18	0.02	0.94	0.44
Firmness[f]	1.9	2.1	2.3	1.7	2.0	2.1	0.16	0.31	0.74	0.56
Drip loss, %	4.68	3.85	4.26	5.73	4.64	4.78	0.932	0.98	0.81	0.60
WHC, %[g]	29.82	31.69	32.02	29.87	33.06	32.03	1.508	0.25	0.53	0.35
L*	54.49	54.68	53.46	53.85	54.42	53.81	0.837	0.63	0.69	0.96
a*	7.98	7.86	8.36	8.71	8.15	8.18	0.270	0.36	0.97	0.33
b*	16.67	16.75	16.90	17.16	16.87	16.91	0.271	0.41	0.80	0.51
630/580	2.66	2.66	2.72	2.72	2.68	2.77	0.062	0.44	0.22	0.95
Temperature, °C										
45 min[h]	38.18	37.58	37.98	38.00	38.37	37.12	0.318	0.30	0.02	0.14
1 h	36.89	36.65	37.19	37.04	37.37	36.35	0.426	0.95	0.22	0.22
24 h[I]	–0.03	–0.26	0.03	0.03	0.11	0.01	0.096	0.94	0.53	0.08
pH										
45 min	6.40	6.36	6.39	6.31	6.29	6.41	0.084	0.58	0.66	0.25
1 h	6.24	6.16	6.15	6.19	6.21	6.24	0.078	0.53	0.54	0.98
24 h	5.44	5.49	5.49	5.46	5.49	5.48	0.021	0.06	0.56	0.28

[a]Values represent the mean of eight observations per treatment (four barrows and four gilts).
[b]Control vs added niacin.
[c]Scoring system of 1 to 5: 1 = pale pinkish gray, 2 = grayish pink, 3 = reddish pink, 4 = purplish red, and 5 = dark purplish red.
[d]Scoring system of 1 to 5: 1 = practically devoid, 2 = traces to slight, 3 = small to modest, 4 = moderate to slightly abundant, and 5 = moderately abundant.
[e]Quadratic ($P < 0.04$) when comparing 0 to 110 mg/kg of niacin.
[f]Scoring system of 1 to 3: 1 = soft and exudative, 2 = slightly firm and moist, and 3 = firm and unexudative.
[g]Water-holding capacity, derived by the area of the meat by the area of the fluid after compression with a Carver Press.
[h]0 vs 550 mg/kg ($P < 0.02$); 110 vs 550 mg/kg ($P < 0.01$).
[i]Linear ($P < 0.07$) when comparing 0 to 110 mg/kg of niacin.

Table 6. Effects of added dietary niacin on growth performance of growing-finishing pigs (Exp. 2)[a]

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[b]	Linear	Quadratic
d 0 to 117										
ADG, g[c]	760	775	762	775	754	753	6.1	0.58	0.06	0.48
ADFI, g[d]	2,168	2,154	2,141	2,070	2,064	2,075	27.0	0.03	0.05	0.01
Gain:feed[d]	0.35	0.36	0.36	0.38	0.37	0.37	0.004	0.01	0.20	0.01
Initial weight, kg	36.2	36.4	36.2	36.1	36.2	36.2	0.26	0.93	0.85	0.83
Final weight, kg	126.3	128.9	125.6	128.5	125.5	125.8	0.86	0.58	0.17	0.42

[a]Values represent the means of eight observations per treatment (four barrows and four gilts) with 26 pigs per pen and a total of 1,248 pigs (intially 36.2 kg). There were no treatment × sex interactions ($P > 0.35$).
[b]Control vs added niacin.
[c]Quadratic ($P < 0.06$) when comparing 0 to 110 mg/kg of niacin.
[d]Linear ($P < 0.002$) when comparing 0 to 110 mg/kg of niacin; 0 vs 550 mg/kg ($P < 0.02$).

$P < 0.04$) b* values. However, most of the differences found in objective color are evident when comparing the control treatment to 550 mg/kg niacin. Adding 550 mg/kg niacin decreased (0 vs 550 mg/kg, $P < 0.003$) L* values and tended to decrease (0 vs 550 mg/kg, $P < 0.10$) a* and b* values. When evaluating a* and b* values as niacin increased from 0 to 110 mg/kg, no differences ($P > 0.20$) were evident. There were also sex × treatment interactions ($P < 0.03$) for a* and reflectance values. Increasing dietary niacin to 110 mg/kg decreased a* values for gilts (8.31, 7.35, 7.92, 6.78, 6.69, and 7.08) while increasing values for barrows (8.13, 7.80, 8.08, 9.52, 9.46, 7.46). Ratio of reflectance (680:580), a measure of oxymyoglobin to metmyoglobin ratio, is another measure of redness that responded similarly. Also, increasing dietary niacin increased (linear, $P < 0.02$) 45-min temperature and 24-h pH of the LM (linear, $P < 0.001$), but had no effect ($P > 0.37$) on 24-h temperature.

Discussion

The effects of feeding increasing added niacin on growth performance and pork quality were not as evident

Table 7. Effects of added dietary niacin on carcass characteristics of growing-finishing pigs (Exp. 2)

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[a]	Linear	Quadratic
Values from pigs harvested at Kansas State University Meat Laboratory[b]										
Hot carcass weight, kg[c]	85.5	88.4	87.8	86.6	86.4	87.7	1.39	0.24	0.68	0.76
Dress, %	75.2	75.2	76.1	74.6	74.8	75.7	0.57	0.94	0.55	0.27
Cold carcass weight, kg[c]	84.5	87.9	87.1	85.7	85.8	86.8	1.37	0.16	0.73	0.86
Shrink, %	1.20	0.58	0.86	0.97	0.68	1.01	0.145	0.02	0.51	0.14
Fat-free lean, %	53.54	54.42	53.10	52.65	51.85	53.05	1.194	0.69	0.76	0.18
Backfat, mm										
First rib[d]	37.2	37.7	40.1	37.4	39.2	35.6	1.85	0.70	0.23	0.45
Last rib[d]	24.2	21.5	24.7	23.3	25.4	23.4	1.21	0.68	0.95	0.20
Last lumbar[d]	15.2	14.2	16.3	14.7	16.3	15.0	1.36	0.97	0.88	0.49
Tenth rib[d]	18.7	17.6	20.3	19.6	20.2	19.3	1.57	0.69	0.83	0.35
Average[d]	25.5	24.5	27.0	25.1	27.0	24.7	1.39	0.94	0.54	0.35
Length, cm[d]	86.9	87.1	84.9	86.7	86.4	85.8	0.80	0.44	0.46	0.89
Loin eye, cm^{2d}	44.9	46.1	46.3	43.2	40.8	44.1	2.80	0.78	0.74	0.16
Values from pens of pigs harvested at commercial slaughter facilities[e]										
Hot carcass weight, kg	96.4	97.0	96.4	96.1	95.1	95.5	0.65	0.63	0.20	0.11
Dress, %	77.1	76.4	76.5	75.9	76.5	76.4	0.35	0.06	0.60	0.32
Fat-free lean, %	52.62	52.36	52.43	52.43	52.51	52.22	0.26	0.41	0.39	0.92
Avg. backfat, mm[f]	16.8	17.1	17.3	17.1	17.4	17.6	0.39	0.25	0.20	0.48
Loin depth, mm[fg]	58.9	58.9	60.0	58.5	59.7	58.8	0.62	0.73	0.59	0.46

[a]Control vs. added niacin.
[b]Values represent the mean of eight observations (four barrows and four gilts) per treatment.
[c]Sex × treatment interaction ($P < 0.04$): weight of gilts was increased at 55 and 110 mg/kg of niacin, whereas weight of barrows decreased.
[d]HCW used as covariate (87.1 kg).
[e]Values represent the means of eight observations (pens) per treatment. Each individual observation represented the mean values of approximately 25 pigs in each pen.
[f]Hot carcass weight used as covariate (96.1 kg).
[g]Sex × treatment interaction ($P < 0.01$): values for gilts were decreased while barrows increased at 110 mg/kg of niacin.

Table 8. Effects of added dietary niacin on longissimus (10th rib) quality of growing-finishing pigs (Exp. 2)[a]

	Added dietary niacin, mg/kg							Contrasts, $P <$		
Item	0	13	28	55	110	550	SEM	Niacin[b]	Linear	Quadratic
Color[chj]	3.9	3.8	3.9	3.3	4.2	4.4	0.19	0.86	0.01	0.89
Marbling[d]	1.1	1.2	1.2	1.4	1.3	1.6	0.21	0.39	0.15	0.73
Firmness[e]	2.4	2.4	2.5	2.3	2.4	2.6	0.18	0.75	0.42	0.82
Wetness[fg]	2.4	2.6	2.4	2.4	2.7	2.9	0.13	0.15	0.01	0.45
Drip loss, %[h]	2.00	1.90	1.93	1.90	1.23	0.80	0.469	0.39	0.04	0.41
L*[gj]	53.12	53.60	53.14	53.95	51.43	49.77	0.733	0.36	0.001	0.35
A*[hk]	8.22	7.57	8.00	8.15	8.07	7.27	0.374	0.33	0.10	0.54
B*[h]	13.33	13.15	12.90	14.24	12.89	12.35	0.404	0.61	0.04	0.76
630/580[jk]	2.59	2.47	2.49	2.54	2.60	2.54	0.061	0.37	0.83	0.38
Temperature, °C										
45 min[gi]	32.9	34.4	34.2	34.3	35.5	36.2	0.80	0.03	0.02	0.13
24 h	0.1	0.2	–0.3	–0.1	0.2	–0.3	0.25	0.64	0.37	0.64
pH										
45 min	6.42	6.42	6.32	6.28	6.29	6.32	0.127	0.51	0.76	0.38
24[gi]	5.67	5.73	5.77	5.76	5.85	5.94	0.049	0.01	0.001	0.06

[a]Values represent the mean of eight observations (four barrows and four gilts) per treatment.
[b]Control vs. added niacin.
[c]Scoring system of 1 to 5: 1 = pale pinkish gray, 2 = grayish pink, 3 = reddish pink, 4 = purplish red, and 5 = dark purplish red.
[d]Scoring system of 1 to 10: score represents percentage intramuscular fat.
[e]Scoring system of 1 to 3: 1 = soft; 2 = firm; and 3 = very firm.
[f]Scoring system of 1 to 3: 1 = exudative, 2 = moist, and 3 = dry.
[g]0 vs 550 mg/kg ($P < 0.01$).
[h]0 vs 550 mg/kg ($P < 0.10$).
[i]Linear ($P < 0.06$) when comparing 0 to 110 mg/kg of niacin.
[j]Quadratic ($P < 0.10$) when comparing 0 to 110 mg/kg of niacin.
[k]Sex × treatment interaction ($P < 0.03$). Values for gilts were decreased at 55 and 110 mg/kg of niacin, whereas values for barrows were increased.

in Exp. 1 as in Exp. 2. Like other studies evaluating pig performance in commercial-type facilities with approximately 25 pigs per pen and greater than 1,000 pigs in a barn (De La Llatta et al., 2001), we observed decreased ADG and ADFI compared to pigs housed in our university research facility. Therefore, growth rate, feed intake, and thus intake of niacin and other nutrients may be contributing factors to some of the variation in response to added niacin we observed between the two trials.

In Exp. 1, pigs consumed 0.02 to 0.03% excess tryptophan (NRC, 1998). Firth and Johnson (1956) showed that pigs could convert every 50 mg of excess tryptophan to 1 mg of niacin. Therefore, pigs could have been converting the excess dietary tryptophan into 13.61 to 9.07 mg/d of niacin. Luce et al. (1967) showed that the niacin in corn is unavailable to the pig, but Yen et al. (1977) reported that the niacin in corn is highly available for chicks. Based on feed intakes, the available niacin in the basal diet, and conversion from excess tryptophan, pigs were consuming 34.7 and 22.6 mg/d niacin compared to requirement estimates of 18.0 and 21.5 mg/d for each of the dietary phases (NRC, 1998). Therefore, differences in growth performance and pork quality were not as evident because pigs were consuming a basal diet that may have provided niacin close to their estimated requirement. In Exp. 2, the available niacin in the basal diets was at or above the requirement estimate (NRC, 1998) from d 0 to 84 but was approximately half of the requirement in the final diet (d 84 to 117).

Determining niacin requirements is challenging due to its conversion from excess tryptophan in the pig (Firth and Johnson, 1956). Despite this, there have been several studies evaluating niacin requirements of pigs. Real et al. (2001) reported maximal growth performance when adding 55 mg/kg of niacin to complex corn–soybean meal diets in early-weaned pigs. Yen et al. (1978) fed added dietary niacin to corn-soybean meal diets to finishing pigs (45 kg BW) and found no benefits in growth performance. Ivers and Veum (1993) reported no differences in growth performance when feeding increasing niacin to pigs consuming low-protein diets in order to minimize conversion of excess tryptophan to niacin. Feed consumption in the experiment of Ivers and Veum (1993) was similar to that found in our first experiment; however, ADG and feed efficiency were lower compared to our study. These differences in diet composition, growth performance, feed intake and lean growth potential of pigs may explain some of the variation in results between our study and earlier studies of Yen et al. (1978) and Ivers and Veum (1993). Considering the wide range of niacin concentrations we evaluated in our studies, the changes in growth performance were relatively small, but do suggest that some supplemental niacin should be added to finishing pig diets.

There has been limited research studying the effect of niacin on meat quality. Piva (1995) reported higher reflectance values and a darker red color of semimembranosus muscle when feeding 75 mg/kg of added niacin to 160 kg pigs for 7 d prior to slaughter compared with control pigs. The authors also reported higher marbling scores when pigs were fed 150 mg/kg of niacin compared with controls. In our first experiment conducted in uni-

versity facilities, niacin had minimal effects on LM quality measurements, although some numerical trends were apparent. In Exp. 2, adding 110 and 550 mg/kg niacin also improved or tended to improve some of the meat quality characteristics. These niacin levels improved subjective color scores, 24-h pH, and lowered L* values and drip loss. Overall, pork quality was better in Exp. 2 than in Exp. 1. This could be due to potential preslaughter stress associated with increased time off feed and the transportation of pigs in Exp. 2 or the different sire lines used in the two studies. Apple et al. (2000) reported an overall higher quality of pork from pigs transported more than 700 km to a commercial harvesting facility vs approximately 5 km to the university abbatoir. These transport distances were similar to those in Exps. 1 and 2.

In the body, niacin is found mainly in the form of NAD+ or nicotinamide adenine dinucleotide phosphate, which function to transfer electrons through the electron transport chain (Groff and Gropper, 2000). In dairy cattle, added dietary niacin improves milk production by enhancing Krebs Cycle and other energy related reactions and preventing ketosis. The improvements observed in meat quality in our experiments from increasing dietary niacin are consistent with lower muscle glycogen and resulting lower lactic acid buildup after death (Grandin, 1980). Glycogen, the storage form of glucose in animals, is converted to lactic acid under anaerobic conditions postmortem. Improvements in energy metabolism and efficiency in muscle from feeding added niacin may result in less glycogen storage as a result of increased efficiency of the electron transport chain. Future studies should include muscle glycogen concentration as response criteria to help confirm this potential mode of action.

Environment and social stress are major factors in determining practical vitamin requirements for pigs, as suggested by the differences in our two experiments. When feeding practical corn–soybean meal-based diets to finishing pigs in commercial facilities, up to 55 mg/kg of added dietary niacin is required to support maximal growth performance. When evaluating requirements to enhance certain pork quality traits, continued improvements up to 110 and 550 mg/kg of added niacin are observed.

Implications

These data suggest that growing-finishing pigs fed practical corn-soybean meal based-diets require approximately 13 to 55 mg/kg added dietary niacin to maximize daily gain and feed efficiency. However, the requirement may be somewhat higher when using the pork quality measurements of color, drip loss percentage, and ultimate pH as response criteria. These estimates are more evident when pigs are reared in a commercial environment than in a university research farm.

Literature Cited

Apple, J. K., C. V. Maxwell, B. deRodas, H. B. Watson, and Z. B. Johnson. 2000. Effect of magnesium mica on performance and carcass quality of growing-finishing swine. J. Anim. Sci. 78:2135–2143.

BASF. 1997. Vitamin supplementation rates for U. S. Commercial Poultry, Swine, and Dairy Cattle. BASF Keeping Current KC 9305. BASF Corp., Mt. Olive, NJ.

CIE. 1976. Supplement No. 2 to CIE Publication No. 15 (E-1.3.1). Recommendations on uniform color spaces-color-difference equations, Pyschometric Color Terms. Commission Internationale de l'Eclairage, Paris.

De La Llata, M., S. S. Dritz, M. D. Tokach, R. D. Goodband, J. L. Nelssen, and T. M. Loughin. 2001. Effects of dietary fat on growth performance and carcass characteristics of growing-finishing pigs reared in a commercial environment. J. Anim. Sci. 79:2643–2650.

Firth, J., and B. C. Johnson. 1956. Quantitative relationships of tryptophan and nicotinic acid in the baby pig. J. Nutr. 59:223–234.

Grandin, T. 1980. The effect of stress on livestock and meat quality prior to and during slaughter. Int. J. Study. Anim. Probl. 1:313.

Grau, R., and R. Hamm. 1956. Determination of water binding in meats by the pressing method. Fleischwirtschaft 8:733–736.

Groff, J. L., and S. S. Gropper. 2000. Advanced Nutrition and Human Metabolism. 3rd ed. Wadsworth/Thomson Learning, Belmont, CA.

Harmon, B. G., D. E. Becker, A. H. Jensen, and D. H. Baker. 1969. Nicotinic acid-tryptophan relationship in the nutrition of the weanling pig. J. Anim. Sci. 28:848–852.

Ivers, D. J., and T. L. Veum. 1993. Effect of niacin additions to corn-soybean meal diets on performance of pigs from weaning to finishing. J. Anim. Sci. 71:3383–3388.

Luce, W. G., E. R. Peo Jr., and D. B. Hudman. 1967. Availability of niacin in corn and milo for swine. J. Anim. Sci. 26:76–84.

NPPC. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Council, Des Moines, IA.

NRC. 1988. Nutrient Requirements of Swine. 9th ed. Natl. Acad. Press, Washington, DC.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Piva, G. 1995. Tranquilizing effect of nicotinic acid and its effects on pork meat and Parma ham quality. Pages 1–7 in Feed Additive News. Lonza, Inc., Fair Lawn, NJ. Real, D. E., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. M. DeRouchey, B. W. James, M. J. Webster, and E. Alonso. 2001. Influence of increasing dietary niacin on starter pig performance. J. Anim. Sci. 79(Suppl. 1):56 (Abstr.).

Yen, J. T., A. H. Jensen, and D. H. Baker. 1977. Assessment of the availability of niacin in corn, soybeans, and soybean meal. J. Anim. Sci. 45:269–278.

Yen, J. T., R. Lauxen, and T. L. Veum. 1978. Effect of supplemental niacin on finishing pigs fed soybean meal supplemented diets. J. Anim. Sci. 47(Suppl. 1):325 (Abstr.).