JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Performance of growing-finishing pigs fed diets containing Roundup Ready corn (event nk603), a nontransgenic genetically similar corn, or conventional corn lines

Y. Hyun, G. E. Bressner, M. Ellis, A. J. Lewis, R. Fischer, E. P. Stanisiewski and G. F. Hartnell

J ANIM SCI 2004, 82:571-580.

Performance of growing-finishing pigs fed diets containing Roundup Ready corn (event nk603), a nontransgenic genetically similar corn, or conventional corn lines

Y. Hyun*, G. E. Bressner*, M. Ellis*[1], A. J. Lewis†, R. Fischer†, E. P. Stanisiewski‡, and G. F. Hartnell†

*Department of Animal Sciences, University of Illinois, Urbana 61801; †Department of Animal Science, University of Nebraska, Lincoln 68583; and ‡Monsanto Company, St. Louis, MO 63167

ABSTRACT: Two studies were conducted at two locations to evaluate growth performance and carcass characteristics of growing-finishing pigs fed diets containing either glyphosate-tolerant Roundup Ready (event nk603) corn, a nontransgenic genetically similar control corn (RX670), or two conventional sources of nontransgenic corn (RX740 and DK647). A randomized complete block design (three and four blocks in Studies 1 and 2, respectively) with a 2 × 4 factorial arrangement of treatments (two genders and four corn lines) was used. Study 1 used 72 barrows and 72 gilts (housed in single-gender groups of six; six pens per dietary treatment) with initial and final BW of approximately 22 and 116 kg, respectively. Study 2 used 80 barrows and 80 gilts (housed in single-gender groups of five; eight pens per dietary treatment) with initial and final BW of approximately 30 and 120 kg, respectively. Pigs were housed in a modified open-front building in Study 1 and in an environmentally controlled finishing building in Study 2. The test corns were included at a fixed proportion of the diet in both studies. Animals had ad libitum access to feed and water. Pigs were slaughtered using standard procedures and carcass measurements were taken. In Study 1, overall ADG, ADFI (as-fed basis), and gain:feed (G:F) were not affected ($P > 0.05$) by corn line. In Study 2, there was no effect of corn line on overall ADFI (as-fed basis) or G:F ratio. In addition, overall ADG of barrows fed the four corn lines did not differ ($P > 0.05$); however, overall ADG of gilts fed corn DK647 was greater ($P < 0.05$) than that of pigs fed the other corn lines. There was no effect ($P > 0.05$) of corn line on carcass yield or fatness measurements in either study. Differences between barrows and gilts for growth and carcass traits were generally similar for both studies and in line with previous research. Overall, these results indicate that Roundup Ready corn (nk603) gives equivalent animal performance to conventional corn for growing pigs.

Key Words: Carcass, Growth, Pigs, Transgenic Corn

 J. Anim. Sci. 2004. 82:571–580

Introduction

Genetically enhanced crops offer producers a wide variety of agronomic benefits. For example, the use of herbicide-tolerant corn, such as Roundup Ready, provides the crop producer with flexible and broad-spectrum postemergent weed control options. Glyphosate, which is the active ingredient in the herbicide Roundup, is one of the most widely used herbicides (Sidhu et al., 2000). Roundup Ready corn (event GA21) was developed to be tolerant to glyphosate by the insertion of a single protein, the modified maize enzyme 5-enolpyruvylshikimate-3-phosphate synthase (**mEPSPS**). Subsequently, a second-generation Roundup Ready corn (containing event nk603) has been developed. This corn expresses CP4 EPSPS protein, which is derived from *Agrobacterium* sp. (Strain CP4). Both EPSPS and CP4 EPSPS proteins are functionally similar to wild-type plant EPSPS enzymes except for a much-reduced affinity for glyphosate (LeBrun et al., 1997). Previous research has demonstrated Roundup Ready corn to be substantially equivalent in nutrient composition to the genetically related nontransgenic corn (Stanisiewski et al., 2001; Taylor et al., 2001).

Because finishing pigs consume large quantities of corn, research was conducted to determine whether pigs fed diets containing a Roundup Ready corn (event nk603) and conventional (nontransgenic) corn have similar performance. Therefore, the objective of this

[1]Correspondence: 216 Animal Sciences Laboratory, 1207 W. Gregory Dr. (phone: 217-333-6455; fax: 217-333-7861; e-mail: mellis7@uiuc.edu).

Received February 19, 2003.

Accepted September 24, 2003.

research was to compare growth performance and carcass quality of growing-finishing pigs fed diets containing either Roundup Ready corn with event nk603, a nontransgenic genetically similar control corn (RX670), or two conventional nontransgenic hybrids (RX740 and DK647).

Materials and Methods

This research consisted of two experiments, with Study 1 being carried out at the University of Nebraska (Lincoln) and Study 2 at the University of Illinois (Urbana). Similar experimental designs and approaches were used at both locations. Experimental protocols were approved by the respective institutional animal care and use committees before the start of the studies.

Animals and Treatments

In Study 1, 144 crossbred (Danbred × [Danbred × NE White line]) pigs (equal numbers of barrows and gilts) with an initial BW of 22.6 ± 0.25 kg were used, and in Study 2, 160 PIC (337 sires × C22 dams) pigs (equal numbers of barrows and gilts) with an initial BW of 29.9 ± 0.54 kg were used.

A randomized complete block design (three and four blocks in Studies 1 and 2, respectively) with a 2 × 4 factorial arrangement of treatments was used. Blocks were based on initial weight and pen location within the building. There were two genders (barrows and gilts) and four genetic corn lines (a transgenic hybrid containing event nk603, the nontransgenic control corn [RX670], and two conventional hybrids [RX740; Asgrow, Des Moines, IA, and DK647; Dekalb Seeds, DeKalb, IA]). Diets contained corn and soybean meal and were fortified with vitamins and minerals to meet or exceed the NRC (1998) requirements for the weights of pigs used. The composition of the corns is presented in Table 1. In Study 1 (Tables 2 and 3), there were four dietary phases (Grower I, 22.6 to 42.9 kg BW; Grower II, 42.9 to 69.7 kg BW; Finisher I, 69.7 to 97.9 kg BW; Finisher II, 97.9 to 116.4 kg BW), and the inclusion rate of the corn was fixed within each phase (68.1, 74.2, 78.1, and 81.8% for Grower I, Grower II, Finisher I, and Finisher II, respectively). Study 1 was carried out for a fixed time period of 103 d, with each diet phase lasting 28 d, except Finisher II, which was 19 d. Study 2 (Table 4) was carried out over a fixed weight range, and there were three dietary phases (Grower [29.9 to 50.1 kg BW], Finisher I [50.1 to 78.7 kg BW], Finisher II [78.7 to 119.4 kg BW]), and the inclusion rate of the corn lines was fixed within each phase (70, 74, and 77% for Grower, Finisher I, and Finisher II, respectively). Diets were changed between phases when the average weight of all pigs in a block reached the designated weight of 50 and 80 kg, respectively.

In Study l, the pigs were housed in a modified-open-front building with 24 pens (pen dimensions [length × width] were 4.8 m × 1.5 m), and each pen contained six pigs, with a floor space of 1.2 m^2/pig. Study 2 was carried out in an environmentally controlled finishing building with part-solid, part-slatted floors and used a total of 32 single-gender pens (barrows or gilts) with five pigs per pen, giving eight pens per dietary treatment. Pen dimensions (length × width) were 2.6 × 1.8 m, giving a floor space of 0.94 m^2/pig. The temperature within the building was controlled by mechanical ventilation linked to a thermostat set at 24°C during the early stages of the study and reduced to 21°C when the pigs reached an average of 50 kg BW. Temperature and humidity levels in the building were recorded on a daily basis using Hobo H8 Loggers (Onset Computer Corp., Bourne, MA). The average temperature during the study was 22.2 ± 2.53°C and the average relative humidity was 52.2 ± 12.46%.

Pigs had ad libitum access to feed and water throughout the experimental period, which ended after 103 d in Study 1 and when the average BW of all the pens of pigs within a block reached approximately 120 kg in Study 2, at which time all pigs in the block were removed from the experiment.

Data and Sample Collection

In both studies, pigs and feeders were weighed and feed intake measured every 2 wk throughout the study, and the amount of feed added to each feeder was recorded to determine ADG, ADFI (as-fed basis), and gain:feed (**G:F**). At the end of the experiment, all pigs were ultrasonically scanned using an Aloka Model 500 B-mode ultrasound scanner fitted with a VST-5021-3 probe (Corometrics Medical Systems, Wallingford, CT). A transverse scan image was taken over the 10th rib, and backfat depth (over the middle of the longissimus muscle) and longissimus muscle area were measured on the scans.

At the end of the experiment, the pigs from the two studies were shipped to different abattoirs and harvested using standard procedures. In Study 1, carcass characteristics were measured using total body electrical conductivity (TOBEC; Model RIPS4; Meat Quality, Inc., Springfield, IL; Forrest et al., 1989). Carcass measurements were taken at 24 h postmortem in Study 1 and included midline fat depths (opposite the first rib, 10th rib, last rib, and last lumbar vertebra), and longissimus muscle area at the 10th rib. In Study 2, carcass measurements were taken at 10 h postmortem and included carcass length (measured from the cranial tip of the aitchbone to the cranial edge of the first rib adjacent to the first thoracic vertebra), midline fat depths (opposite the first rib, last rib, and last lumbar vertebra), 10th-rib fat depth (measured over the longissimus muscle at three-quarters of the distance from the midline), and longissimus muscle depth and area at the 10th rib.

Muscle quality measurements taken on the cut surface of the longissimus muscle at the 10th rib included pH, firmness and marbling scores (NPPC, 1991), and

Table 1. Nutrient composition of the corn lines (as-fed basis)

	Corn line[a]			
Item, %	nk603	RX670	DK647	RX740
Dry matter	87.8	88.3	85.4	86.5
Crude protein	7.35	7.90	7.85	8.13
Crude fat	3.75	3.77	3.43	4.13
ADF	2.9	3.0	3.5	3.8
NDF	9.1	9.6	10.3	9.5
Crude fiber	2.6	2.1	2.7	1.9
Crude ash	7.35	7.35	7.35	7.35
Amino acid composition:				
Arginine	0.29	0.29	0.36	0.26
Histidine	0.21	0.21	0.23	0.22
Isoleucine	0.22	0.23	0.24	0.26
Leucine	0.84	0.93	0.93	1.04
Lysine	0.23	0.25	0.25	0.24
Methionine	0.19	0.17	0.18	0.18
Cysteine	0.18	0.20	0.24	0.24
Phenylalanine	0.36	0.37	0.38	0.40
Tyrosine	0.27	0.23	0.25	0.25
Threonine	0.29	0.30	0.30	0.30
Tryptophan	0.05	0.06	0.06	0.06
Valine	0.31	0.32	0.34	0.35

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.

Minolta L* (lightness), a* (red-green scale), and b* (yellow-blue scale) values in Study 1 and color and firmness and marbling scores in Study 2 (NPPC, 1991, 2000).

In both studies, the chemical composition of the longissimus muscle was determined on a subsample of three pigs randomly selected from within each pen. A longissimus muscle sample was taken at the 10th rib

Table 2. Composition of Grower I and Grower II diets—Study 1 (as-fed basis)

	Corn line in diet[a]							
	nk603		RX670		DK647		RX740	
Ingredient, %	Grower I	Grower II	Grower I	Grower II	Grower I	Grower II	Grower I	Grower II
Corn	68.07	74.21	68.07	74.21	68.07	74.21	68.07	74.21
Soybean meal (dehulled)	26.00	20.25	26.00	20.25	26.00	20.25	26.00	20.25
Tallow	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	1.25	0.85	1.25	0.85	1.25	0.85	1.25	0.85
Limestone	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[b]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Trace mineral premix[c]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tylan[d]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-Lysine·HCl	0.05	0.06	0.05	0.06	0.05	0.06	0.05	0.06
Chemical composition, %[e]								
ME, kcal/kg[f]	3,464	3,480	3,464	3,480	3,464	3,480	3,464	3,480
Crude protein	17.79	15.63	18.16	16.04	18.35	16.00	18.32	16.04
Calcium	0.70	0.60	0.70	0.60	0.70	0.60	0.70	0.60
Phosphorus	0.60	0.50	0.60	0.50	0.60	0.50	0.60	0.50
Lysine	0.95	0.80	0.96	0.82	0.96	0.82	0.96	0.82

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]The vitamin premix supplied per kilogram of diet: vitamin A (as retinyl acetate), 3,088 IU; vitamin D_3 (as cholecalciferol), 386 IU; vitamin E (as α-tocopherol acetate), 15 IU; vitamin K (as menadione sodium bisulfite), 2.3 mg; riboflavin, 3.9 mg; D-pantothenic acid, 15.4 mg; niacin, 23.3 mg; choline, 77.2 mg; vitamin B_{12}, 15.4 μg.
[c]The trace mineral premix supplied per kilogram of diet: Zn (as ZnO), 110 mg; Fe (as $FeSO_4 \cdot H_2O$), 110 mg; Mn (as MnO), 22 mg; Cu (as $CuSO_4 \cdot H_2O$) 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.22 mg; Se (as Na_2SeO_3), 0.3 mg.
[d]Tylan-40 (Elanco Animal Health, Indianapolis, IN); to supply 110 g/kg tylosin in the final feed.
[e]Calculated values based on analyzed values for the corn and soybean meal samples used.
[f]Based on values from NRC (1998).

Table 3. Composition of Finisher I and Finisher II diets—Study 1 (as-fed basis)

	Corn line in diet[a]							
	nk603		RX670		DK647		RX740	
Ingredient, %	Finisher I	Finisher II	Finisher I	Finisher II	Finisher I	Finisher II	Finisher I	Finisher II
Corn	78.11	81.79	78.11	81.79	78.11	81.79	78.11	81.79
Soybean meal (dehulled)	16.25	12.75	16.25	12.75	16.25	12.75	16.25	12.75
Tallow	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	0.93	0.75	0.93	0.75	0.93	0.75	0.93	0.75
Limestone	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[b]	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Trace-mineral premix[c]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tylan[d]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-Lysine·HCl	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Chemical composition, %[e]								
ME, kcal/kg[f]	3,479	3,487	3,479	3,487	3,479	3.487	3,479	3,487
Crude protein	13.53	12.41	13.96	12.46	13.92	12.42	14.14	12.65
Calcium	0.60	0.55	0.60	0.55	0.60	0.55	0.60	0.55
Phosphorus	0.50	0.45	0.50	0.45	0.50	0.45	0.50	0.45
Lysine	0.69	0.60	0.71	0.62	0.71	0.62	0.71	0.62

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]The vitamin premix supplied per kilogram of diet: vitamin A (as retinyl acetate), 3,088 IU; vitamin D_3 (as cholecalciferol), 386 IU; vitamin E (as α-tocopherol acetate), 15 IU; vitamin K (as menadione sodium bisulfite), 2.3 mg; riboflavin, 3.9 mg; D-pantothenic acid, 15.4 mg; niacin, 23.3 mg; choline, 77.2 mg; vitamin B_{12}, 15.4 μg.
[c]The trace mineral premix supplied per kilogram of diet: Zn (as ZnO), 110 mg; Fe (as $FeSO_4 \cdot H_2O$), 110 mg; Mn (as MnO), 22 mg; Cu (as $CuSO_4 \cdot H_2O$) 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.22 mg; Se (as Na_2SeO_3), 0.3 mg.
[d]Tylan-40 (Elanco Animal Health, Indianapolis, IN); to supply 110 g/kg tylosin in the final feed.
[e]Calculated values based on analyzed values for the corn and soybean meal samples used.
[f]Based on values from NRC (1998).

from 18 pigs per treatment (nine barrows and nine gilts) in Study 1 and 24 pigs per treatment (12 barrows and 12 gilts) in Study 2. Longissimus samples were homogenized and analyzed for protein, fat, and moisture using the procedures of Novakofski et al. (1989).

Corn samples from each line were collected before the start of the experiment for nutrient analysis (Table 1). Also, a soybean meal sample was collected at the feed mill during the production of each dietary phase for the determination of crude protein and amino acid concentrations.

Sample Analysis

Corn and soybean meal samples were ground through a 1-mm screen before analysis. Ingredient samples were analyzed in duplicate for crude protein according to AOAC (1995) procedures. Samples were hydrolyzed for 20 h using 6 *N* HCl at 107°C before separation of amino acids by ion-exchange HPLC. After elution, amino acids were quantified fluorometrically using o-phthalaldehyde as a derivatization reagent (AOAC, 1995).

Statistical Analysis

Pen was the experimental unit in both studies. All data (growth, carcass, meat quality, and chemical composition) were analyzed as a randomized complete block design using PROC MIXED procedures of SAS (SAS Institute, Inc., Cary, NC). The effects included in the model were gender (barrows and gilts), corn line (nk603, RX670, RX740, and DK647), block, and gender × corn line interaction. Least squares means were evaluated using the PDIFF and STDERR options of SAS.

Results and Discussion

Growth Performance

In Study 1, ADG, ADFI, and G:F were not affected ($P > 0.05$) by corn line (Table 5). In Study 2 (Table 6), there was a corn line × gender interaction for ADG in the growing phase ($P < 0.05$) and in the overall growth period ($P < 0.05$) as well as for G:F in the Finisher I phase ($P < 0.01$). For barrows, there was no effect ($P > 0.05$) of corn line on ADG during any phase; however, gilts fed DK647 grew faster ($P < 0.05$) than those fed the other lines for the overall growth period and faster than those fed diets with nk603 and RX740 in the growing period (Table 6). During Finisher I, barrows fed diet nk603 had a higher G:F than those fed RX670 and DK647, whereas gilts fed hybrid DK647 had a higher G:F than those fed RX670 (Table 6). However, there was no effect ($P > 0.05$) of corn line on G:F for the overall growth period (Table 6).

Different approaches to diet formulation were used in these two studies. In Study 1, the inclusion rate of all ingredients was the same for all diets within a phase. This approach has the potential disadvantage that the variation in nutrient composition of the test diets could produce differences in animal performance independent of any effect of corn line per se. However, differ-

Table 4. Composition of the diets—Study 2 (as-fed basis)

	Corn line in diet[a]											
	nk603			RK670			DK647			RX740		
Ingredient, %	Grower	Finisher I	Finisher II	Grower	Finisher I	Finisher II	Grower	Finisher I	Finisher II	Grower	Finisher I	Finisher II
Corn	65.00	74.00	77.00	65.00	74.00	77.00	65.00	74.00	77.00	65.00	74.00	77.00
Soybean meal (dehulled)	28.80	19.20	15.30	27.43	17.80	13.50	30.19	21.10	17.20	27.50	18.00	13.90
Wheat middlings	2.43	3.12	3.84	3.98	4.69	5.78	0.00	0.05	0.72	3.06	3.52	4.37
Soybean oil	1.44	1.58	1.80	1.26	1.38	1.63	2.48	2.75	3.04	2.10	2.34	2.20
Dicalcium phosphate	0.92	0.78	0.68	0.85	0.73	0.63	0.92	0.82	0.72	0.85	0.77	0.65
Limestone	0.80	0.73	0.68	0.85	0.78	0.74	0.80	0.71	0.66	0.85	0.75	0.73
L-Lysine·HCl	0.01	0.04	0.03	0.04	0.06	0.06	0.00	0.00	0.00	0.04	0.06	0.05
DL-Methionine	0.03	0.06	0.11	0.02	0.05	0.09	0.05	0.08	0.12	0.02	0.05	0.10
Threonine	0.02	0.04	0.09	0.02	0.05	0.10	0.01	0.04	0.08	0.02	0.05	0.09
Tryptophan	0.00	0.00	0.02	0.00	0.01	0.02	0.00	0.00	0.01	0.01	0.01	0.02
Tylan[b]	0.05	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00	0.05	0.05	0.00
Trace-mineral premix[c]	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[d]	0.15	0.10	0.10	0.15	0.10	0.10	0.15	0.10	0.10	0.15	0.10	0.10
Chemical composition, %[e]												
ME, kcal/kg[f]	3,370	3,383	3,395	3,370	3,383	3,395	3,370	3,383	3,395	3,369	3,382	3,394
Crude protein	18.53	14.95	13.58	18.46	14.92	13.43	18.48	14.97	13.56	18.53	15.03	13.60
Calcium	0.61	0.52	0.47	0.61	0.52	0.47	0.61	0.52	0.47	0.61	0.52	0.47
Phosphorus	0.58	0.53	0.50	0.61	0.55	0.53	0.57	0.51	0.48	0.58	0.54	0.50
Lysine	1.02	0.78	0.67	1.02	0.78	0.67	1.02	0.78	0.67	1.02	0.78	0.67

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]Tylan-40 (Elanco Animal Health, Indianapolis, IN); to supply 44 g/kg tylosin in the final feed.
[c]The vitamin premix supplied per kilogram of diet: vitamin A (as retinyl acetate), 3,088 IU; vitamin D_3 (as cholecalciferol), 386 IU; vitamin E (as α-tocopherol acetate), 15 IU; vitamin K (as menadione sodium bisulfite), 2.3 mg; riboflavin, 3.9 mg; D-pantothenic acid, 15.4 mg; niacin, 23.3 mg; choline, 77.2 mg; vitamin B_{12}, 15.4 µg.
[d]The trace mineral premix contained 84% salt and supplied per kilogram of diet: Zn (as ZnO), 110 mg; Fe (as $FeSO_4 \cdot H_2O$), 110 mg; Mn (as MnO), 22 mg; Cu (as $CuSO_4 \cdot H_2O$) 11 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.22 mg; Se (as Na_2SeO_3), 0.3 mg.
[e]Calculated values based on analyzed values for the corn and soybean meal samples used.
[f]Based on values from NRC (1998).

Table 5. Least squares means for effects of corn line and gender on growth performance—Study 1

Item	Corn line in diet[a] nk603	RX670	DK647	RX740	SEM	Gender Barrow	Gilt	SEM
Number of pens	6	6	6	6	—	12	12	—
Initial weight, kg	22.5	22.6	22.6	22.6	0.03	22.8	22.4	0.02
Final weight, kg	116.4	116.5	116.7	116.2	1.48	121.1[b]	111.7[c]	1.05
Grower I (28 d from 22.6 to 42.9 kg)								
Average daily gain, g	724	716	748	715	13.3	750[b]	710[c]	9.4
Average daily feed intake, kg[d]	1.45	1.42	1.47	1.42	0.023	1.48	1.40	0.016
Gain:feed	0.50	0.50	0.51	0.50	0.004	0.50	0.50	0.003
Grower II (28 d from 42.9 to 69.7 kg)								
Average daily gain, g	945	956	956	957	13.9	1025[b]	882[c]	9.9
Average daily feed intake, kg[d]	2.27	2.31	2.26	2.28	0.042	2.46[b]	2.11[c]	0.030
Gain:feed	0.42	0.41	0.42	0.42	0.003	0.42	0.42	0.002
Finisher I (28 d from 69.7 to 97.9 kg)								
Average daily gain, g	1,019	984	1,022	1,016	21.1	1,061[b]	956[c]	14.9
Average daily feed intake, kg[d]	2.90	2.92	2.84	2.86	0.066	3.11[b]	2.65[c]	0.047
Gain:feed	0.35	0.35	0.35	0.36	0.004	0.34[c]	0.36[b]	0.003
Finisher II (19 d from 97.9 to 116.4 kg)								
Average daily gain, g	983	973	976	967	23.9	1,010[b]	940[c]	16.9
Average daily feed intake, kg[d]	3.19	3.09	3.11	3.06	0.067	3.32[b]	2.91[c]	0.047
Gain:feed	0.31	0.32	0.31	0.32	0.005	0.30[c]	0.32[b]	0.003
Overall (103 d from 22.6 to 116.4 kg)								
Average daily gain, g	912	912	910	909	13.9	956[b]	866[c]	9.8
Average daily feed intake, kg[d]	2.39	2.38	2.36	2.35	0.043	2.53[b]	2.21[c]	0.030
Gain:feed	0.38	0.38	0.39	0.39	0.003	0.38[c]	0.39[b]	0.002

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b,c]Within a treatment and row, means without a common superscript letter differ ($P < 0.05$).
[d]As-fed basis.

Table 6. Least squares means for effects of corn line and gender on growth performance—Study 2

Item	Corn line in diet[a] nk603	RX670	DK647	RX740	SEM	Gender Barrow	Gilt	SEM
Number of pens	8	8	8	8	—	16	16	—
Initial weight, kg	30.0	30.2	29.8	29.7	0.26	30.1	29.8	0.18
Final weight, kg	119.4	118.4	121.8	118.0	1.31	123.1[d]	115.7[e]	0.92
Grower (29.9 to 50.1 kg)								
Average daily gain, g[b]								
Barrow	818[d]	789[def]	801[de]	821[d]	30.2	—	—	—
Gilt	710[f]	772[def]	850[d]	717[ef]	—	—	—	—
Average daily feed intake, kg[h]	1.64	1.71	1.77	1.68	0.052	1.74	1.66	0.037
Gain:feed	0.47	0.46	0.47	0.46	0.011	0.47	0.46	0.008
Finisher I (50.1 to 78.7 kg)								
Average daily gain, g	968	996	1,053	1,007	27.0	1,061[d]	950[e]	19.1
Average daily feed intake, kg[h]	2.37	2.59	2.59	2.51	0.064	2.68[d]	2.35[e]	0.046
Gain:feed[b]								
Barrow	0.42[de]	0.38[g]	0.39[fg]	0.40[efg]	0.008	—	—	—
Gilt	0.40[defg]	0.39[fg]	0.42[d]	0.41[def]	—	—	—	—
Finisher II (78.7 to 119.4 kg)								
Average daily gain, g	1,069	1,011	1,042	1,017	25.5	1,071[d]	999[e]	18.0
Average daily feed intake, kg[h]	3.05	3.01	3.00	2.94	0.064	3.18[d]	2.81[e]	0.045
Gain:feed	0.35	0.34	0.35	0.35	0.006	0.34[e]	0.36[d]	0.004
Overall (29.9 to 119.4 kg)								
Average daily gain, g[c]								
Barrow	1017[d]	981[d]	975[d]	1009[d]	20.3	—	—	—
Gilt	892[e]	904[e]	996[d]	881[e]	—	—	—	—
Average daily feed intake, kg[h]	2.46	2.52	2.54	2.46	0.042	2.63[d]	2.35[e]	0.030
Gain:feed	0.39	0.37	0.39	0.38	0.004	0.38[e]	0.39[d]	0.003

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]Corn line × gender interaction ($P < 0.05$).
[c]Corn line × gender interaction ($P < 0.01$).
[d,e,f,g]Within a treatment and an interaction, means without a common superscript letter differ ($P < 0.05$).
[h]As-fed basis.

Table 7. Least squares means for the effects of corn line and gender on ultrasound and carcass measurement—Study 1

	Corn line in diet[a]					Gender		
Item	nk603	DK647	RX670	RX740	SEM	Barrow	Gilt	SEM
Number of pens	6	6	6	6	—	12	12	—
Ultrasound measurements								
Backfat thickness, cm	2.10	2.05	2.07	2.07	0.008	2.31[e]	1.84[f]	0.057
Longissimus muscle area, cm^2	48.4	47.9	48.9	46.8	0.88	48.1	47.9	0.62
Backfat thickness, cm								
1st rib	4.74	4.75	4.81	4.76	0.153	4.94[e]	4.59[f]	0.108
10th rib	3.08	2.98	2.97	3.00	0.075	3.27[e]	2.74[f]	0.053
Last rib	3.50	3.38	3.43	3.61	0.103	3.65[e]	3.31[f]	0.073
Last lumbar	2.36	2.31	2.27	2.31	0.076	2.53[e]	2.10[f]	0.054
Longissimus muscle area, cm^2	56.6	58.6	56.6	55.3	2.02	55.2	58.3	1.43
TOBEC measurements								
Hot carcass weight, kg	88.8	89.0	88.7	88.4	1.27	92.1[e]	85.3[f]	0.898
Ham weight, kg	10.7	10.3	10.1	10.2	0.12	10.2	10.2	0.09
Loin weight, kg	12.0	12.1	11.9	11.7	0.15	12.0	11.8	0.10
Shoulder weight, kg	12.3	12.4	12.3	12.2	0.17	12.5	12.2	0.12
Primal, %[b]	38.9	39.0	38.9	38.7	0.37	37.8[f]	40.0[e]	0.26
Total fat-free lean, kg[c]	42.1	42.4	42.2	42.6	0.60	45.1	44.0	0.42
Percentage of fat-free lean[c]	47.6	47.5	47.7	48.2	0.50	49.0[f]	51.5[e]	0.42
Lean gain, g/d[d]	338	341	339	343	5.5	345	336	3.9

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.

[b]Calculated as the total weight of the primals (ham, loin, and shoulder) divided by the hot carcass weight.

[c]Estimated from total body electrical conductivity (TOBEC) scans.

[d]Lean gain = (final fat-free lean – initial fat-free lean)/103 d; initial fat-free lean 0.95 × [–3.95 + (0.418 × live weight, kg)].

[e,f]Within a treatment and row, means without a common superscript differ ($P < 0.05$).

ences in nutrient composition among the test diets were small (Tables 2 and 3). In Study 2, the corn inclusion level was fixed within a phase. Diets were formulated to the same nutrient composition resulting in variable inclusion rates across the corn line diets for other ingredients, particularly soybean meal, wheat middlings, and soybean oil. This approach has the potential disadvantage that variation in ingredient inclusion rate could affect growth. However, differences among the diets for the four corn lines in ingredient inclusion rates were relatively small (Table 4) and were unlikely to have affected animal performance.

Thus, results for both genders in Study l and barrows in Study 2 suggest that the Roundup Ready corn gave equivalent growth performance to the nontransgenic control corn (RX670) and the conventional hybrids tested. For the gilts in Study 2, during the overall growth period one of the commercial corns (DK647) elicited greater ($P > 0.05$) growth rates but similar feed efficiencies than the other three hybrids. The growth rate of gilts fed DK647 was similar to that of barrows on the same treatment, a finding that is contrary to most studies that have compared castrates and gilts (Cromwell et al., 1993; Hahn et al., 1995; Stanisiewski et al., 2001). In addition, for the overall growth period gilts in Study 2 fed nk603 corn had performance similar to those fed the other two lines tested (RX670 and RX740). Thus, the difference in growth rate between the corn lines for gilts was more a function of the better performance of animals on one of the conventional hybrids rather than being due to any negative effect of the Roundup Ready corn on growth. Diets based on DK647 had the lowest inclusion of wheat middlings and the highest inclusion of soybean oil (Table 4), and this potentially could have contributed to the observed difference in overall growth rate among corn lines in gilts. However, it is unlikely that the inclusion rate differences in this study, which were relatively small, would have affected the relative growth of pigs on the four test corn treatments.

There are limited data in the scientific literature comparing transgenic with nontransgenic conventional corn fed to pigs. However, research carried out with poultry has shown results similar to the present study, with no differences in growth rate, feed conversion efficiency, or fat pad weight among broilers fed Roundup Ready corn (event GA21 or nk603), the nontransgenic control corn, or conventional corn hybrids (Sidhu et al., 2000; Taylor et al., 2001).

In both studies, barrows had higher ($P < 0.05$) overall ADFI and ADG than gilts (Tables 5 and 6). In addition, gilts had higher ($P < 0.01$) G:F ratio than barrows in Finishers I and II and overall (Tables 5 and 6). These results are similar to those of most previous research that has evaluated the growth performance of castrates and gilts (Labroue et al., 1994; Hahn and Baker, 1995; Hyun and Ellis, 2001).

Table 8. Least squares means for the effects of corn line and gender on ultrasound and carcass measurements, and longissimus muscle quality and composition—Study 2

	Corn line in diet[a]					Gender		
Item	nk603	RX670	DK647	RX740	SEM	Barrow	Gilt	SEM
Number of pens	8	8	8	8	—	16	16	—
Ultrasound measurements								
Backfat thickness, cm	1.50	1.47	1.50	1.48	0.034	1.63[d]	1.34[e]	0.024
Longissimus muscle area, cm[2b]								
Barrow	45.9[e]	44.1[efg]	42.8[fgh]	44.5[ef]	0.92	—	—	—
Gilt	40.3[hi]	41.5[ghi]	43.3[efg]	39.9[i]	—	—	—	—
Carcass measurements								
Cold carcass weight, kg[b]								
Barrow	89.9[e]	86.8[e]	87.4[e]	89.7[e]	1.78	—	—	—
Gilt	80.4[f]	81.4[f]	88.6[e]	80.1[f]	—	—	—	—
Dressing percent	71.3	71.0	72.2	71.9	0.68	71.8	71.4	0.48
Carcass length, cm	84.8	84.1	85.0	84.1	0.39	84.7	84.4	0.28
Backfat thickness, cm								
1st rib	4.08	4.08	4.15	3.95	0.109	4.21[d]	3.91[e]	0.077
Last rib	2.25	2.30	2.28	2.25	0.091	2.44[d]	2.09[e]	0.064
Last lumbar vertebra	1.79	1.73	1.85	1.71	0.080	1.99[d]	1.55[e]	0.056
10th rib	1.94	1.90	1.94	1.86	0.100	2.13[d]	1.69[e]	0.071
Longissimus muscle area, cm^2	42.2	42.9	43.4	41.9	0.85	42.2	42.9	0.60
Longissimus muscle color[c]	2.29	2.25	2.26	2.20	0.117	2.26	2.24	0.083
Longissimus muscle firmness[bc]								
Barrow	2.15[ef]	2.30[ef]	2.73[e]	2.33[ef]	0.192	—	—	—
Gilt	2.40[e]	2.33[ef]	1.75[f]	2.20[ef]	—	—	—	—
Longissimus muscle marbling[c]	1.43	1.41	1.15	1.14	0.112	1.36	1.21	0.079
Chemical composition of longissimus muscle, %[d]								
Moisture	73.16	73.34	73.42	73.23	0.140	73.12	73.45	0.099
Protein	23.39	23.35	23.13	22.92	0.241	23.33	23.06	0.170
Fat	2.77	2.78	2.46	2.83	0.160	2.79	2.62	0.113

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]Corn line × gender interaction ($P < 0.05$).
[c]Evaluated on 5- or 6-point scales. Color: 1 = light to 6 = dark; firmness: 1 = soft to 5 = very firm; marbling: 1 = devoid to 6 = abundant.
[d]Based on a subsample of three pigs per pen.
[e,f,g,h,i]Within a treatment and an interaction, means without a common superscript letter differ ($P < 0.05$).

Carcass Characteristics

There was no effect ($P > 0.05$) of corn line on any of the carcass measures taken in Study 1 (Table 7). Additionally, none of the TOBEC measurements differed ($P > 0.05$) among the corn lines (Table 7). In Study 1, TOBEC measurements for hot carcass weight, shoulder weight, and total lean weight were greater for barrows than gilts. However, gilts had a greater percentage of primal cuts and percentage fat-free lean than barrows (Table 7). The TOBEC estimates of primal weights were similar to the directly measured wholesale primal weights reported by Gu et al. (1992) and Cisneros et al. (1996). In addition, Unruh et al. (1996) reported that when barrows and gilts were fed to an end weight of 127 kg, the primal percentage was greater in gilts than in barrows. In the current study, the higher shoulder weight for barrows was a result of their greater slaughter weight than gilts (121 vs. 112 kg, respectively). Previous studies have shown that at a similar slaughter weight, gilts produce carcasses with a greater percentage of lean than barrows (Cromwell et al., 1993; Unruh et al., 1996). Carcass fat-free lean gain, calculated from TOBEC measurements, was not affected ($P > 0.05$) by either gender or corn line (Table 7). Most studies have also shown similar lean growth rates for barrows and gilts.

In Study 2, corn line × gender interactions ($P < 0.05$) were detected for ultrasound longissimus muscle area and cold carcass weight (Table 8). Barrows fed hybrid DK647 had lower ($P < 0.05$) longissimus muscle area than those fed nk603, whereas gilts fed DK647 had greater longissimus muscle area than those fed nk603 and RX740 (Table 8). However, there was no corn line × gender interaction ($P > 0.05$) for longissimus muscle area measured on the carcass (Table 8). For barrows, there was no effect of corn line on cold carcass weight, whereas gilts that were fed hybrid DK647 had heavier ($P < 0.01$) carcass weights than those fed the other corn lines (Table 8). However, there was no corn line × gender interaction ($P > 0.05$) for dressing percent, suggesting that variation in cold carcass weight for gilts resulted from differences in live weight at slaughter.

In both studies, barrows had greater ($P < 0.05$) backfat thickness than gilts; however, there was no difference ($P > 0.05$) between the genders for longissimus muscle area measured on the carcass (Tables 7 and 8). The difference in backfat depth between barrows and gilts was similar to the results of Cromwell et al. (1993) and Hahn et al. (1995); however, in those experiments,

Table 9. Least squares means for the effects of corn line and gender on longissimus muscle quality and composition—Study 1

	Corn line in diet[a]					Gender		
Item	nk603	RX670	DK647	RX740	SEM	Barrow	Gilt	SEM
Number of pens	6	6	6	6	—	12	12	—
Longissimus muscle quality measurements								
Marbling[b]	2.00	2.03	2.00	2.00	0.014	2.00	2.01	0.010
Firmness[b]	2.08	2.22	1.93	2.08	0.096	2.04	2.12	0.068
Ultimate pH	5.64	5.60	5.63	5.63	0.016	5.65[d]	5.61[e]	0.012
Minolta L*	50.69	50.59	50.78	49.75	0.623	50.37	50.53	0.440
Minolta a*	7.40	7.17	6.71	7.20	0.262	7.12	7.12	0.185
Minolta b*	2.58	2.51	2.39	2.11	0.294	2.43	2.37	0.208
Chemical composition of the longissimus muscle, %[c]								
Protein	23.51	23.78	23.48	23.74	0.216	23.77	23.49	0.153
Fat	2.99	2.20	3.06	3.08	0.247	3.08	2.59	0.174
Moisture	72.53	72.71	72.40	72.31	0.262	72.37	72.60	0.185

[a]nk603 = transgenic Roundup Ready corn; RX670 = nontransgenic control corn; RX740 and DK647 = conventional corn hybrids.
[b]Evaluated using a five-point scale: 1 = soft and devoid of marbling to 5 = firm and abundant or greater marbling.
[c]Based on a subsample of three pigs per pen.
[d,e]Within a treatment and row, means without a common superscript letter differ ($P < 0.05$).

gilts had greater longissimus muscle area than barrows, which is in contrast to the results of the present studies. The lack of a gender effect on longissimus muscle area could, in part, be due to differences in slaughter live weight between barrows and gilts. However, fitting live weight at slaughter as a covariate in the model removed the gender difference in carcass weight, but it did not produce a difference ($P > 0.05$) among the genders in longissimus muscle area.

Longissimus Muscle Quality

In Study 1, there was no effect ($P < 0.05$) of corn line on any muscle quality or composition measurement (Table 9). Similarly, in Study 2, longissimus muscle chemical composition and color and marbling scores were similar ($P > 0.05$) across corn lines (Table 8). There was an interaction ($P < 0.05$) between corn line and gender for longissimus muscle firmness. For barrows, there was no effect ($P < 0.05$) of corn line on muscle firmness; however, gilts fed DK647 had lower scores, indicating softer muscle, than those fed nk603 (Table 8). There is no obvious explanation for this interaction. Gilts fed DK647 did grow faster than gilts fed the other corns (Table 6), but there were no treatment interactions ($P > 0.05$) for muscle color scores and fat content, two factors that can be associated with muscle firmness. Nevertheless, there was no evidence from these two studies of any negative effect of the test corn (nk603) on pork quality. This finding is similar to that of Stanisiewski et al. (2001), who reported no effects of a Roundup Ready corn (event GA21) compared with conventional hybrids on chemical composition of muscle. Pork quality is of increasing importance to the swine industry, and these results suggest no difference between the Roundup Ready hybrid tested relative to the conventional corns for longissimus muscle quality.

Muscle quality and composition measurements were generally similar ($P > 0.05$) for barrows and gilts in both studies (Tables 8 and 9) with the exception that in Study 1 ultimate pH values were greater ($P < 0.05$) for barrows than gilts (Table 9); however, the differences between the genders was small. Most previous studies have indicated that meat quality measurements, including ultimate pH, are similar for barrows and gilts (Unruh et al., 1996; Nold et al., 1999).

Implications

These studies demonstrated that the feeding value of Roundup Ready corn (containing event nk603, which expresses the CP4 EPSPS protein) is similar to that of the nontransgenic control corn and the conventional corn lines tested. Therefore, Roundup Ready corn (event nk603) when used in swine diets can be expected to have effects on growth performance and carcass characteristics comparable to those of conventional corn.

Literature Cited

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Cisneros, F., M. Ellis, F. K. McKeith, J. McCaw, and R. L. Fernando. 1996. Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. J. Anim. Sci. 74:925–933.

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. C. Ewan, C. R. Hamilton, A. J. Lewis, D. C. Mahan, E. R. Miller, J. E. Pettigrew, L. F. Tribble, and T. L. Veum. 1993. The dietary protein and(or) lysine requirement of barrows and gilts. J. Anim. Sci. 71:1510–1519.

Forrest, J. C., C. H. Kuei, M. W. Orcutt, A. P. Schinckel, J. R. Stouffer, and M. D. Judge. 1989. A review of potential new methods of on-line pork carcass evaluation. J. Anim. Sci. 67:2164–2170.

Gu, Y., A. P. Schinckel, and T. G. Martin. 1992. Growth, development, and carcass composition in five genotypes of swine. J. Anim. Sci. 70:1719–1729.

Hahn, J., and D. H. Baker. 1995. Optimum ratio to lysine of threonine, tryptophan and sulfur amino acids for finishing swine. J. Anim. Sci. 73:482–489.

Hahn, J. D., R. R. Biehl, and D. H. Baker. 1995. Ideal digestible lysine level for early- and late-finishing swine. J. Anim. Sci. 73:773–784.

Hyun, Y., and M. Ellis. 2001. Effect of group size and feeder type on growth performance and feeding patterns in growing pigs. J. Anim. Sci. 79:803–810.

Labroue, F., R. Gueblez, P. Sellier, and M. C. Meunier-Salaun. 1994. Feeding behaviour of group-housed Large White and Landrace pigs in French Central Test Stations. Livest. Prod. Sci. 40:303–312.

LeBrun, M., A. Sailland, and G. Freyssinet. 1997. Mutated 5-enolpyruvylshikimate-3-phosphate synthase, gene coding of said protein and transformed plants containing said gene. International Patent Application WO 97/04103,1997.

Nold, R. A., J. R. Romans, W. J. Costello, and G. W. Libal. 1999. Characterization of muscles from boars, barrows, and gilts slaughtered at 100 and 110 kilograms: Differences in fat, moisture, color, water-holding capacity, and collagen. J. Anim. Sci. 77:1746–1754.

Novakofski, J., S. Park, P. J. Bechtel, and F. K. McKeith. 1989. Composition of cooked pork chops: Effect of removing subcutaneous fat before cooking. J. Food Sci. 54:15–17.

NPPC. 1991. Procedures to Evaluate Market Hogs. National Pork Producers Council, Des Moines, IA.

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

NRC. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.

Sidhu, R. S., B. G. Hammond, R. L. Fuchs, J. N. Mutz, L. R. Holden, B. George, and T. Olson. 2000. Glyphosate-tolerant corn: The composition and feeding value of grain from glyphosate tolerant corn is equivalent to that of conventional corn (Zea mays L.). J. Agric. Food Chem. 48:2305–2312.

Stanisiewski, E. P., G. F. Hartnell, and D. R. Cook. 2001. Comparison of swine performance when fed diets containing Roundup Ready® corn (GA21), parental line or conventional corn. J. Anim. Sci. 79 (Suppl. 1):319 (Abstr.).

Taylor, M. L., G. F. Hartnell, M. A. Nemeth, B. George, and J. D. Astwood. 2001. Comparison of broiler performance when fed diets containing YieldGard® corn, Yieldguard® and Roundup Ready® corn, parental lines, or commercial corn. Poultry Sci. 80 (Suppl. 1): 319. (Abstr.)

Unruh, J. A., K. G. Friesen, S. R. Stuewe, B. L. Dunn, J. L. Nelssen, R. D. Goodband, and M. D. Tokach. 1996. The influence of genotype, sex, and dietary lysine on pork subprimal cut yields and carcass quality of pigs fed to either 104 or 127 kilograms. J. Anim. Sci. 74:1274–1283.