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Growth, pork quality, and excretion characteristics of pigs fed Bt corn or non-transgenic corn

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Abstract

Two experiments (exp. 1 and exp. 2, respectively) were conducted to compare performance, pork quality, and excretion characteristics of pigs fed diets containing Bt 11 (Bt) or control corn (C: non-transgenic inbred lines for exp. 1, and a non-transgenic isoline for exp. 2). Experiment 1 involved barrows and gilts (total $n = 64$; initial BW = 64 kg and 60 kg), while in exp. 2, 120 barrows were used (initial BW = 17 kg). Pigs were allocated to pens, blocked by sex and BW. Isocaloric, isolysinic diets contained an indigestible marker in exp. 1. Feed disappearance and weight gain data, and excreta samples were collected weekly in exp. 1. Feed disappearance and weight gain data were collected weekly in exp. 2. No difference in ADG was observed, however, feed efficiency was greater for pigs fed the C diet. No corn effects were observed for hot carcass weight, loin eye area, or backfat depth. Hunter color 'b' values and values for chroma were significantly greater for pigs fed C diets ($P = 0.02$, < 0.01, respectively) in exp. 1. In contrast, Hunter color 'b' values were significantly lower for pigs fed C diets ($P = 0.05$) in exp. 2. No corn effects were observed for proximate analyses of meat samples, N or P content of fecal and urine samples, nor N digestibility. Pigs fed C diets had greater apparent P digestibility (57.8% vs. 40.2%; $P < 0.0001$).

Keywords

Bt corn, Animal performance, Excretion

Disciplines

Agriculture | Animal Sciences | Meat Science

Comments

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Growth, pork quality, and excretion characteristics of pigs fed Bt corn or non-transgenic corn

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Custodio, M. G., Powers, W. J., Huff-Lonergan, E., Faust, M. A. and Stein, J. 2006. **Growth, pork quality, and excretion characteristics of pigs fed Bt corn or non-transgenic corn**. Can. J. Anim. Sci. **86**: 461–469. Two experiments (exp. 1 and exp. 2, respectively) were conducted to compare performance, pork quality, and excretion characteristics of pigs fed diets containing Bt 11 (Bt) or control corn (C: non-transgenic inbred lines for exp. 1, and a non-transgenic isoline for exp. 2). Experiment 1 involved barrows and gilts (total $n = 64$; initial BW = 64 kg and 60 kg), while in exp. 2, 120 barrows were used (initial BW = 17 kg). Pigs were allocated to pens, blocked by sex and BW. Isocaloric, isolysinic diets contained an indigestible marker in exp. 1. Feed disappearance and weight gain data, and excreta samples were collected weekly in exp. 1. Feed disappearance and weight gain data were collected weekly in exp. 2. No difference in ADG was observed, however, feed efficiency was greater for pigs fed the C diet. No corn effects were observed for hot carcass weight, loin eye area, or backfat depth. Hunter color 'b' values and values for chroma were significantly greater for pigs fed C diets ($P = 0.02$, < 0.01, respectively) in exp. 1. In contrast, Hunter color 'b' values were significantly lower for pigs fed C diets ($P = 0.05$) in exp. 2. No corn effects were observed for proximate analyses of meat samples, N or P content of fecal and urine samples, nor N digestibility. Pigs fed C diets had greater apparent P digestibility (57.8% vs. 40.2%; $P < 0.0001$).

Key words: Bt corn, animal performance, excretion

Custodio, M. G., Powers, W. J., Huff-Lonergan, E., Faust, M. A. et Stein, J. 2006. **La croissance, la qualité de la viande et l'excrétion chez les porcs nourris de maïs Bt ou de maïs non transgénique**. Can. J. Anim. Sci. **86**: 461–469. Les auteurs ont entrepris deux expériences afin de comparer le rendement, la qualité de la viande et l'excrétion chez des porcs recevant une ration à base de maïs Bt 11 (Bt) ou de maïs ordinaire (T : lignées autogames non transgéniques pour la première expérience et isolignée non transgénique pour la seconde). La première expérience portait sur des castrats et des truies nullipares ($n = 64$; poids corporel initial de 64 kg et de 60 kg, respectivement) alors que la seconde portait sur 120 castrats (poids corporel initial de 17 kg). Les animaux ont été répartis dans des enclos en fonction du sexe et du poids corporel. Pour la première expérience, on s'est servi de rations isocaloriques et isolysiniques contenant un marqueur indigestible. Chaque semaine, les auteurs ont recueilli des données sur l'ingestion des aliments et le gain de poids ainsi que des échantillons d'excréments; dans la seconde expérience, ils se sont limités aux données sur l'ingestion des aliments et le gain de poids. On n'observe aucune variation du gain quotidien moyen, mais les porcs nourris avec la ration T présentaient un meilleur indice de consommation. Le maïs n'a aucune incidence sur le poids de la carcasse chaude, la superficie de la longe et l'épaisseur du gras dorsal. Les valeurs colorimétriques de l'échelle « b » de Hunter et la chrominance étaient significativement plus élevées chez les sujets recevant la ration T ($P = 0{,}02$ et $P < 0{,}01$, respectivement) dans la première expérience, alors que dans la seconde, les valeurs colorimétriques de l'échelle « b » de Hunter étaient significativement plus faibles ($P = 0{,}05$). L'analyse immédiate des échantillons de viande, la concentration de N ou de P dans les fèces et l'urine et la digestibilité du N ne révèlent aucun effet attribuable au maïs. Les animaux nourris avec la ration T se caractérisaient par une meilleure digestibilité apparente du P (57,8 % c. 40,2 %; $P < 0{,}0001$).

Mots clés: Maïs Bt, rendement des animaux, excrétion

Recent advances in biotechnology have brought enormous changes in agriculture. One of these changes is the introduction of novel genes into crops to improve yield and/or quality. One such crop that has been developed by genetic engineering is Bt corn. Bt corn was produced by incorporating a gene from a naturally occurring bacterium, *Bacillus thuringiensis* (Bt). This organism expresses a gene that encodes for crystal-like proteins that kill a specific group of insects. For many years, the practice of spraying Bt as a biopesticide in corn fields was conducted as a means of controlling an economically important pest, the European corn borer (*Ostrinia nubilalis*). However, this practice required repeated application and necessitated the use of insecticides. To overcome these disadvantages, plant scientists inserted the *Bt* gene directly into corn DNA.

The Bt 11 corn variety was developed to be both insect-resistant and herbicide-tolerant. It was genetically engineered through the introduction of the *cry1Ab* gene from *Bacillus thuringiensis* and the *pat* gene from *Streptomyces viridochromogenes* (Agbios 2003). Direct DNA transfer

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served as the method of introduction for these foreign genes in Bt corn (Koziel et al. 1993). The *cry1Ab* gene expresses the cry1Ab protein, a delta-endotoxin for the control of the European corn borer. The *pat* gene regulates the expression of phosphinothricin N-acetyltransferase (PAT), an enzyme that metabolizes the herbicide, glufosinate (Agbios 2003). The *cry1Ab* proteins demonstrate tissue-specific expression and have been shown to be expressed in leaf, root, pollen, and kernels of corn (US EPA 2000).

Genetic modification of corn raises questions of whether the nutritive value of the crop is unintentionally altered and, hence, might potentially affect the growth and performance of food animals in a negative manner. The objective of this research was to compare the growth performance, carcass and meat quality, and excretion characteristics of pigs fed diets containing either Bt event 11 corn, non-transgenic Bt isoline, or combined corn from non-transgenic inbred lines.

MATERIALS AND METHODS

This research consisted of two experiments, conducted in 2 consecutive years. The first experiment consisted of a shorter-term feeding study to establish pig performance and nutrient digestibility during the finisher phase and carcass characteristics when pigs were slaughtered at a lighter US market weight, closer to a European market weight of 85 kg. The second experiment studied the effects over the entire grow-finish period and was intended to illustrate corn effects on pig performance and carcass characteristics at a typical US slaughter weight only. Both experiments were conducted at Iowa State University facilities with protocols approved by the institution's Committee on Animal Care.

Animals and Treatments

Experiment 1

Sixty-four Yorkshire pigs (an equal number of barrows and gilts) with an average initial BW of 61.15 ± 0.88 kg (mean ± SD) were allocated in pens, four pigs per pen, blocked by BW and sex so as to minimize BW variation within a pen and match pen BW between treatments. The experiment was a 2 × 2 factorial with factors of corn source (Bt; Bt 11, Syngenta Seeds, Inc., Golden Valley, MN or C; combined corn grains from a number of non-transgenic inbred lines; Table 1) and sex (G; gilt or B; barrow with diets formulated to accommodate the nutrient requirement differences between male and female animals; Table 2). The diets were referred to as control-gilt (C-G), control-barrow (C-B), Bt-gilt (Bt-G), and Bt-barrow (Bt-B). There were four pens assigned to each of the four diets (C-G, C-B, Bt-G, Bt-B) with four pigs per pen. Diets contained corn and soybean meal fortified with vitamins and minerals to meet the NRC (1998) requirements and were adjusted as the experiment progressed based on the growth phase of the animals. Diets were formulated to be offered over the course of three feeding phases (Phase 1 = 60–80 kg BW; Phase 2 = 81–90 kg BW; Phase 3 = > 91 kg BW). Control and Bt diets were formulated to be isocaloric and isolysinic based on lysine, energy, total and non-phytin P content analyses conducted prior to formulation (Table 1). Diets contained Celite 281® (World Minerals, Inc., Santa Barbara, CA), an inert, indigestible diatomaceous earth that was used as a marker to determine nutrient digestibilities (Vogtmann et al. 1975) in lieu of metabolism crates for the nutrient digestibility measures. The percent of Celite in the diet was allowed to fluctuate between approximately 0.95 and 1.50% based on how much could be accommodated and still meet energy needs of the diet. Sucrose was added as a high-energy feed to the diets and was needed to makeup for dietary space that was occupied by the indigestible marker. Dicalcium phosphate addition varied in the diet in order to supply similar Ca and P contents across treatments.

Table 1. Analyzed nutrient content of control and Bt 11 corn grains (exp. 1, wet basis)

Nutrient (%)	Bt 11	Control
Crude fat	3.01	3.27
Protein	7.45	8.71
Arginine	0.32	0.36
Cystine	0.21	0.22
Isoleucine	0.23	0.28
Lysine	0.25	0.27
Methionine	0.16	0.18
Threonine	0.27	0.31
Tryptophan	0.06	0.07
Tyrosine	0.18	0.20
Valine	0.32	0.38
Moisture	11.49	11.05
Phytate phosphorus	0.26	0.21
Total phosphorus	0.32	0.29
Non-phytate phosphorus[z]	0.06	0.09

[z] Calculated as the difference between analyzed total and phytate phosphorus.

Experiment 2

One hundred-twenty barrows (equal number of Yorkshire and Yorkshire × Duroc) with an average initial BW of 17.57 ± 0.72 kg (mean ± SD) were used to evaluate Bt corn when directly substituted for conventional corn. Pigs were allocated in pens, six pigs per pen, blocked by sex and BW to minimize BW variation within a pen and providing similar pen BW between treatments. Each pen was assigned to either a diet with Bt corn (Bt; Bt 11, Syngenta Seeds, Inc., Golden Valley, MN) or a diet with control corn (C; non-transgenic Bt isoline). Diets contained corn and soybean meal fortified with vitamins and minerals to meet the NRC (1998) requirements and were adjusted as the experiment progressed based on the growth phase of the animals (Table 3). There was a total of three phases for the duration of the experiment (Phase 1 = 17–43 kg; Phase 2 = 43–73 kg; Phase 3 = 73–120 kg). Based on the results from exp. 1 and the use of corn isolines for this experiment, a direct substitution of the treatment corn was made for the control corn in the Bt diets to relate more directly to the commercial practice not analyzing each corn batch. Previously analyzed composition of the Bt corn (exp. 1) was used in the formulation process. The experiment was a factorial design with two corn sources.

In both experiments, pigs were housed in an environmentally controlled building with concrete-floored pens and sidewall curtains so as to maintain an indoor temperature between 14 and 18°C. Both experiments were conducted

Table 2. Ingredients and nutrient composition of diets[z] (exp. 1)

	Phase 1 (60–80 kg)				Phase 2 (81–90 kg)				Phase 3 (91–110+ kg)			
Ingredient (%)	C-G	C-B	Bt-G	Bt-B	C-G	C-B	Bt-G	Bt-B	C-G	C-B	Bt-G	Bt-B
Corn[y,x]												
Control	77.50	83.00	–	–	77.60	77.00	–	–	81.00	83.00	–	–
Bt corn	–	–	78.00	82.30	–	–	77.60	77.00	–	–	83.00	83.00
Soybean meal	15.70	11	15.95	11.70	12.50	9.60	13.05	10.10	9.90	8.75	9.30	9.30
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
KSU trace mineral mix [w]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
KSU trace vitamin mix [v]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Calcium carbonate	0.99	1.00	0.93	0.93	0.98	1.01	0.92	0.94	1.04	1.05	0.97	0.97
Dicalcium phosphate	0.53	0.33	0.64	0.45	0.40	0.26	0.51	0.38	0.24	0.19	0.31	0.31
Celite	1.17	1.02	1.03	0.97	1.57	1.98	1.42	1.88	1.47	1.06	0.95	0.95
Sucrose	3.66	3.20	3.00	3.20	6.50	9.70	6.05	9.25	5.90	5.50	5.02	5.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Formulated analyses (as-fed basis)												
ME (kcal kg^{-1})	3,298	3,306	3,298	3,307	3,303	3,309	3,304	3,309	3,320	3,320	3,320	3,320
Lysine (%)	0.68	0.56	0.68	0.56	0.59	0.50	0.59	0.50	0.52	0.49	0.49	0.49
Total P	0.44	0.38	0.48	0.43	0.39	0.34	0.44	0.39	0.35	0.34	0.39	0.39
Non-phytin P (%)	0.19	0.15	0.19	0.15	0.16	0.13	0.16	0.13	0.13	0.12	0.12	0.12
Ca (%)	0.59	0.56	0.59	0.56	0.52	0.49	0.52	0.49	0.50	0.49	0.50	0.49
Analyzed composition (dry matter basis)												
TKN (%)	2.26	2.11	2.13	1.80	2.05	1.79	2.03	1.82	2.26	1.97	2.09	1.89
Lysine, %	0.74	0.64	0.72	0.67	0.60	0.53	0.60	0.61	0.74	0.58	0.71	0.64
Methionine (%)	0.29	0.29	0.28	0.27	0.25	0.24	0.28	0.26	0.28	0.24	0.26	0.26
Threonine (%)	0.59	0.53	0.55	0.52	0.51	0.46	0.53	0.48	0.58	0.50	0.53	0.49
Total P (%)	0.41	0.36	0.39	0.38	0.37	0.38	0.43	0.38	0.43	0.28	0.40	0.37
Ca (%)	0.61	0.59	0.57	0.59	0.48	0.51	0.51	0.51	0.51	0.49	0.57	0.52
GE (kcal kg^{-1})	4218	4234	4212	4240	4224	4254	4218	4244	4248	4268	4239	4260

[z] C and Bt indicate corn source (control and transgenic); G and B indicate gilts and barrows, respectively.

[y] Corn source = combined grains from a number of non-transgenic modified inbred lines.

[x] Corn source = Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).

[w] Provided per kilogram of complete diet: 11 mg Cu ($CuSO_4$), 110 mg Zn (ZnO), 26 mg Mn (MnO), 11 mg Fe ($FeSO_4$), 198 µg I (EDDI), and 198 µg Se (Na_2SeO_3).

[v] Provided per kilogram of complete diet: 9091 IU of vitamin A, 1363 IU of vitamin D_3, 36 IU of vitamin E, 3.6 mg of menandione, 0.03 mg of vitamin B_{12}, 40 mg of niacin, 23 mg of pantothenic acid, 7 mg of riboflavin.

Table 3. Ingredients and nutrient composition of diets[z] (exp. 2)

	Phase 1 (17–43 kg)		Phase 2 (44–73 kg)		Phase 3 (73 – 120 kg)	
Ingredient (%)	C	Bt	C	Bt	C	Bt
Corn[y,x]						
control	70.00		72.55		76.50	
Bt corn		70.00		72.55		76.50
Soybean meal	25.25	25.25	22.50	22.50	19.75	19.75
Mineral, vitamin, salt mix [w]	2.50	2.50	2.50	2.50	1.25	1.25
Fat	2.15	2.15	2.35	2.35	2.45	2.45
Lysine	0.10	0.10	0.10	0.10	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Formulated analyses (as-fed basis)						
Lysine (%)	1.03	1.03	0.95	0.95	0.84	0.84
Total P	0.56	0.56	0.46	0.46	0.42	0.42
Non-phytin P (%)	0.37	0.37	0.27	0.27	0.17	0.17
Ca (%)	0.75	0.75	0.61	0.61	0.56	0.56
Analyzed composition (dry matter basis)						
TKN (%)	3.38	3.28	3.33	3.28	2.84	2.95
Lysine (%)	1.15	1.04	0.96	0.91	0.78	0.80
Methionine (%)	0.31	0.28	0.28	0.26	0.26	0.26
Threonine (%)	0.75	0.65	0.63	0.60	0.56	0.60
Total P (%)	0.62	0.61	0.52	0.50	0.460.42	
Ca (%)	0.81	0.83	0.64	0.65	0.61	0.59
GE (kcal kg^{-1})	4486	4493	4459	4463	4417	4413

[z] C and Bt indicate corn source (control and transgenic).

[y] Corn source = non-transgenic isoline.

[x] Corn source = Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).

[w] Provided per kilogram of complete diet: 11 mg Cu ($CuSO_4$), 110 mg Zn (ZnO), 26 mg Mn (MnO), 11 mg Fe ($FeSO_4$), 198 µg I (EDDI), 198 µg Se (Na_2SeO_3), 9091 IU of vitamin A, 1363 IU of vitamin D_3, 36 IU of vitamin E, 3.6 mg of menandione, 0.03 mg of vitamin B_{12}, 40 mg of niacin, 23 mg of pantothenic acid, 7 mg of riboflavin and 20 mg of NaCl.

during winter months. Pen dimensions were 3.5 m × 2.3 m, providing a floor space of 2.01 m^2 pig^{-1}. Each pen was provided with one nipple drinker and one Smidley-Ranger self-feeder (Marting Manufacturing of Iowa, Inc., Britt, IA). Entry to the building required observance of biosecurity protocols set forth by the farm.

All diets were mixed at a commercial feed mill. Pigs were allowed ad libitum access to feed and water throughout the duration of both experiments. To minimize feed wastage, feeders were filled daily so that the following day, the amount of feed left was just enough to cover the bottom of the feeder. Feeders were checked daily and adjusted accordingly such that the amount offered each day was estimated to be 10% greater than the anticipated consumption for that day. The amount of feed offered to each pen was recorded daily, and feed disappearance was determined weekly. The amount of feed remaining in the feeder at the end of each week was subtracted from the total feed offered during the week to estimate the total feed consumed. Pigs were individually weighed and the average pen weight was calculated weekly. Pigs were harvested at an average weight of 95 kg and 120 kg in exp. 1 and 2, respectively.

Data and Sample Collection

In exp. 1, fecal and urine samples were collected from each pig, weekly, throughout the duration of the study. Urine and fecal grab samples were collected from each pig by catching feces and urine, as voided, using plastic containers. Employees arrived at the facility first thing in the morning to feed, at which time pigs would get up and urinate and defecate. Both excretions were collected from each individual pig, midstream. Fecal samples for each pen were pooled using approximately 50 g of feces from each pig. The samples were dried in aluminum pans, in a forced-air oven (55°C). Dried feces were ground using a Thomas-Wiley Intermediate Mill (3383-L10 series Thomas Scientific, Swedesboro, NJ) with a 20 mesh sieve and stored until analyses. To prevent cross-contamination of Bt and control samples, all C diets and fecal samples were ground in advance of the Bt diet and fecal samples and the mill was cleaned and sanitized between sample groups. The urine samples were pooled, by pen, reserving approximately 20 mL from each pig. Pooled urine samples were transferred to 50-mL capacity plastic tubes with caps and frozen at –20°C until analyses.

Digestibility of N and P estimates were made by including the indigestible marker in the feed during exp. 1 and relating the concentration of that marker present in collected fecal samples to the N and P content of the fecal samples in order to estimate fecal mass.

Feed samples were collected from each pen and then pooled by diet in both experiments. Samples were sent to Dairy One Forage Testing Laboratory (Ithaca, NY) for proximate and mineral analyses and to Experiment Station Chemical Laboratories, University of Missouri (Columbia, MO) for amino acid analyses. Feed samples were stored then analyzed for N, P, and DM content at Iowa State University. In exp. 1, acid insoluble ash (AIA) was measured in feed and fecal samples to determine the digestibility estimates. Urine samples were analyzed for N and P content. Fecal samples were analyzed for N, P, DM and AIA content. All analytical procedures were conducted according to the Association of Official Analytical Chemists (AOAC) (1995).

At the end of both exps. 1 and 2, the pigs were harvested at the Iowa State University Meat Laboratory using standard procedures. Carcasses were chilled for 24 h in a forced-air cooler at –5°C. The drop in the temperature of the carcasses was recorded at 1, 6, and 24 h post-slaughter using a digital probe thermometer (Thermocouple Thermometer Model 600–1040, Barnant Co., Barrington, IL). Likewise, carcass pH was measured using a pH meter with a glass body penetration probe (pH-STAR Pistol Model 5000, SFK Technology Inc., Cedar Rapids, IA) at the same time points. Both temperature and pH measurements were obtained from the area of the longissimus dorsi at the 12th rib on the right side of the carcass. Loin eye area and backfat thickness (1st rib, 10th rib, last rib, and last lumbar vertebrae) were measured 24 h post-slaughter. Boneless loin samples were collected 24 h post-slaughter. Samples were obtained from the longissimus dorsi of the left side of the carcass. From each of the carcasses, three 2.54-cm-thick loin chops were collected for color analysis (*L*, *a*, and *b* values) using a HunterLab LabScan Instrument (Hunter Associates Laboratories, Inc., Reston, VA). Hue angle was calculated based on these color analyses. Hue angle was calculated as $\tan^{-1}(b/a)$ (Minolta 1994). Chroma was calculated as the square root of the sum of the a value, squared plus the b value, squared (Minolta, 1994). Further description of hue angle and chroma are provided by Rentfrow et al. (2004). These same chops were used for analysis of drip loss by weight difference after color analysis had been conducted (Gardner et al. 2006). Two 2.54-cm-thick chops were collected for analysis of tenderness (star probe analysis) (Gardner et al. 2006) One 2.54-cm thick sample was collected for proximate analyses. All analytical procedures were conducted according to AOAC (1990, 1993).

Statistical Analyses

The pen was the experimental unit in both experiments. All data were analyzed using the PROC GLM procedure of SAS (SAS Institute, Inc. 1990). The effects included in the model were treatment (Bt vs. control) and sex (barrows vs. gilts, exp. 1 only) and the interaction of treatment and sex (exp. 1 only). All data were pooled across feeding phases. Values were reported as least squares means from the PDIFF and STDERR options of SAS. Statistical significance was declared at $P < 0.05$.

RESULTS AND DISCUSSION

Growth Performance

During exp. 1 no pigs were removed, nor did any pigs die during the experiment. Two pigs from each treatment group died or were removed from the experiment for health reasons during exp. 2.

In exp. 1, ADFI and ADG were not affected by the type of corn present in the diet (Table 4). However, in exp. 2,

Table 4. Effects of corn line and sex on growth performance of growing-finishing swine (exp. 1)

	Dietary treatments[y,x]				SEM	*P* values		
Parameter[z]	C-G	C-B	Bt-G	Bt-B		Treatment	Sex	Treatment × Sex
Initial weight	58.7	63.1	59.5	63.4	0.88	0.53	<.01	0.83
Final weight	92.8	100.0	92.2	99.5	1.82	0.75	<.01	0.96
ADFI (kg)	2.28	2.77	2.31	2.78	0.07	0.91	<.01	0.97
ADG (kg)	0.73	0.83	0.72	0.80	0.03	0.53	<.01	0.88
FCR (feed:gain)	3.11	3.35	3.22	3.46	0.03	0.003	<.01	0.94

[z] FCR, feed conversion ratio.

[y] C and Bt indicate corn source (control and transgenic); G and B indicate gilts and barrows, respectively.

[x] Four pigs per pen; 16 pigs per treatment.

ADFI was greater in pigs that consumed diets with Bt corn, while ADG was not affected by corn type (Table 5). Feed conversion ratio (feed:gain) was greater in pigs fed diets containing Bt corn in both experiments, suggesting that pigs fed diets with the control corn were more efficient feed converters. Because of the feeding process that was used to minimize feed wastage from grouped pigs, we expect that feed wastage was similar between treatments, though no measures were able to be made in the housing system used. In exp. 1, gender had an effect on ADG, with barrows gaining 91 g d^{-1} more than gilts (Table 3; $P < 0.01$). However, feed:gain was greater for barrows compared with gilts ($P < 0.0001$), indicating that gilts were more efficient feed converters compared with barrows. There were no significant interactions observed between type of corn and gender.

Table 5. Effects of corn line on growth performance of growing-finishing swine (mean ± SE; exp. 2)

	Dietary treatment[y,x]		
Parameter[z]	Bt	Control	P value
Initial weight (kg)	17.8 ± 0.72	17.3 ± 0.73	0.60
Final weight (kg)	120.1 ± 1.61	118.5 ± 1.63	0.47
ADFI (kg)	2.28 ± 0.01	2.19 ± 0.013	<0.01
ADG (kg)	0.83 ± 0.01	0.82 ± 0.01	0.32
FCR (feed:gain)	2.74 ± 0.01	2.69 ± 0.01	<0.01

[z] FCR, feed conversion ratio.

[y] Bt, Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN); Control: Bt 11 non-transgenic isoline.

[x] Six barrows per pen; 10 pens per treatment.

The results of the two experiments showed that corn type had no consistent effect on feed intake and average daily gain. This is consistent with other feeding trials which compared genetically modified corn and conventional corn varieties (Weber et al. 2000; Reuter et al. 2001; Stanisiewski et al. 2001; Fischer et al. 2002; Bressner et al. 2002; Hyun et al. 2004). In contrast, Piva et al. (2001) found that average daily gain was greater in pigs fed Bt corn (MON 810), and the difference was attributed to lower fumonisin B_1 concentrations in Bt corn grains (not measured in this study). In contrast with the findings of Hyun et al. (2004), wherein, feed:gain was not affected by corn type, the current experiments demonstrated greater feed:gain in pigs fed Bt corn, perhaps indicative of similar fumonisin B_1 concentrations between corn sources.

Excretion Characteristics

Excretion characteristics were considered in the first experiment, only. An indigestible marker was fed throughout the study in order to gain apparent digestibility estimates from each pen, without housing individual animals in metabolism crates. In exp. 1, the mass of feces excreted (g d^{-1}) was greater for barrows than gilts, but was not different between pigs fed Bt and control corn (Table 6). Intake of N (g d^{-1}) was significantly greater in pigs fed the control corn and in barrows. However, there were treatment × sex interactions observed for N intake, which may have been influenced by the much greater intake of barrows fed the control corn. The amount of N in feces did not differ in pigs fed Bt and control corn. Barrows, however, excreted an average of 8 g more N in feces compared with gilts. There were no interactions observed for N in feces between treatment groups. Percentage N in urine did not differ between pigs fed Bt and control corn, but was significantly greater in gilts than barrows. Phosphorus intake (g d^{-1}) was also greater in pigs fed the control corn and in barrows. There was an interaction between treatment and gender for P intake, which may have been influenced by the greater P intake in barrows fed the control corn (Table 6). The amount of P in feces (g d^{-1}) did not differ between pigs fed Bt and control corn, but was significantly greater in barrows compared with gilts. There were no interactions observed for fecal P between treatment groups.

Apparent digestibility of N was 1.4 percentage units greater in pigs fed control corn than those fed the Bt corn, and 2.9 percentage units greater in gilts compared with barrows. On the other hand, apparent digestibility of P was 17.6 percentage units greater in pigs fed control corn, but was 8.5 percentage units greater in barrows compared with gilts. Treatment × gender interactions were observed for apparent digestibility of N, with barrows fed Bt corn and gilts fed control corn having lower percent apparent N digestibility (Table 6). Treatment × gender interactions were also observed for apparent digestibility of P, with barrows fed control corn and gilts fed Bt corn having greater percent apparent P digestibility.

At present, no data in scientific literature about excretion of N and P in pigs fed transgenic corn are available to com-

Table 6. Least square means of N and P in feces and urine from pigs fed Bt (B) and control diets (C) (exp. 1)[z]

	Treatments[y]					P value for		
Item	C-G	C-B	Bt-G	Bt-B	SEM	Treatment	Sex	Treatment × Sex
Feces excreted (DM) (g d^{-1} pen^{-1})	1035.0	1281.9	1090.6	1384.7	40.7	0.05	<0.0001	0.56
Nitrogen								
N intake (g d^{-1} pen^{-1})	183.2	209. 8	178.1	185.9	3.9	<0.01	<0.01	0.02
Fecal N (g d^{-1} pen^{-1})	33.0	40.1	31.8	40.4	1.4	0.75	<0.01	0.59
Urinary N (%)	1.12	0.96	1.08	0.84	0.08	0.29	<0.01	0.57
Apparent digestibility of N (%)	81.6	80.3	81.7	77.3	0.7	0.05	0.01	0.03
Phosphorus								
P intake (g d^{-1} pen^{-1})	50.2	50.8	44.6	47.1	3.2	<0.01	<0.01	<0.01
Fecal P (g d^{-1} pen^{-1})	24.7	28.3	23.8	28.5	0.9	0.70	<0.01	0.53
Apparent digestibility of P (%)	47.4	40.6	42.1	38.32.8	<0.01	<0.01	<0.01	

[z]Pooled data from five collection dates.

[y]Four pens per treatment; four pigs per pen; C and Bt indicate corn source (control and transgenic); G and B indicate gilts and barrows, respectively.

pare the results of the current experiment. The results, however, suggest that excretion of N and P are not negatively affected by genetic alteration of corn. Aulrich et al. (2001) demonstrated that the Bt and non-Bt varieties of corn fed had no significant difference in metabolizable energy (ME) values, nitrogen free extract (NFE), and protein digestibility. At this time we have no explanation for depressed N and P digestibility in the Bt corn-fed pigs. Other studies have reported on in vitro digestibility assessments of genetically modified crops (Jung et al. 2004) however, no swine studies are available in the literature to compare in vivo digestibility effects. The apparent N digestibility values reported in the current study are, however, slightly greater than other literature values (78.4%, Moeser et al. 2002). Grab samples of feces and urine were collected from pigs, so while N digestibility measures lead one to suspect N volatilization, methods used in this study would not have resulted in greater volatilization than would occur using metabolism crates. Apparent P digestibility values in the current study are similar to those reported by Mroz et al. (2000).

Carcass and Meat Quality Characteristics

In exp. 1, no differences were observed between carcass characteristics obtained from pigs fed Bt corn and pigs fed control corn (Table 7). No treatment effects were observed for loin eye area (LEA), star probe values (tenderness), percent drip loss, and chemical composition of longissimus muscle (Table 8). For the longissimus muscle color, significant differences were observed only for the *b* value. A higher *b* value denotes greater intensity of yellow color. Results suggest that pigs fed control corn had longissimus muscle with greater yellow color (higher Hunter *b* value) compared with pigs fed Bt corn. The reason for the differences in *b* value may be due to differences in fat content between the two corn varieties; however, because the diets were formulated to be isocaloric, and because the differences in *b* value, while significant, were small, it is difficult to determine the cause. Hue angle, used to indicate discoloration (Hunt and Mancini 2002), was not different between treatments ($P >$ 0.05). However, chroma values were greater in samples from pigs fed diets containing the control corn, indicating greater color saturation (reddish-pink color) in these samples. Overall, while color was more intense in samples from pigs fed the control corn, interpretation of all color measures does not clearly indicate a difference in consumer preference.

Barrows, in general, were 7.25 kg heavier than gilts at slaughter. However, barrows and gilts had an average carcass yield of 71.61 and 72.11%, respectively, which were not statistically different ($P = 0.39$; Table 7). No difference ($P = 0.15$) was observed in the first rib backfat between gilts (29.76 mm) and barrows (31.55 mm). However, barrows had thicker 10th rib (20.28 mm vs.14.13 mm; $P < 0.0001$), last rib (19.48 mm vs. 16.63 mm; P = 0.01), and last lumbar vertebrae (19.52 mm vs. 14.41 mm; $P < 0.0001$) backfat compared with gilts (Table 7). In addition, barrows had five percentage units less carcass lean compared with gilts (51.03% vs. 56.22%; P < 0.0001). Gilts had significantly larger LEA than barrows. The LEA from gilts were bigger than LEA from barrows by 1.65 cm^2 (14.87 cm^2 vs. 13.22 cm^2; P = 0.006). As expected, pigs slaughtered at a 100 kg weight had larger LEA compared with those harvested at 85 kg. The LEA from heavier pigs was larger by 3.27 cm^2 (15.68 cm^2 vs. 12.41 cm^2; $P < 0.0001$).

The average ultimate temperature of carcasses from gilts was 1.48°C which was 1.2°C lower than that of barrow carcasses (P < 0.0001; Table 7). Barrow carcasses, both from control and Bt treatments, were warmer compared with those of the gilts. It can be noted that barrow carcasses, both from the control and Bt treatments, had numerically higher pH at 1 h post-slaughter compared with gilt carcasses. However, the extent of pH decline of barrow carcasses appeared to be greater compared with the gilt carcasses. Average pH_u of barrow carcasses was 5.35 and was significantly lower compared with pH_u of gilt carcasses, which was 5.49 ($P = 0.0001$; Table 7).

No differences between sex were observed for longissimus muscle tenderness and percentage drip loss (Table 8). For the longissimus muscle color, no differences were observed for *L* and *a* values or for hue angle. However, the *b* value for longissimus muscle obtained from gilt carcasses was greater (11.79 vs. 11.23; $P = 0.002$; Table 8) as was the

Table 7. Comparison of corn and sex effects on carcass characteristics of pigs fed Bt corn and control corn (exp. 1)

	Corn line[z][y]			Sex			
Item	Control	Bt	*P*-value	Gilts	Barrows	*P* value	SEM
Slaughter weight (kg)	96.43	95.86	0.75	92.52	99.77	<.01	1.28
Hot carcass weight (kg)	69.97	68.46	0.29	66.74	71.69	<.01	1.00
Carcass yield (%)	72.43	71.29	0.06	72.11	71.61	0.39	0.45
Backfat (mm)							
1st rib	30.7	30.6	0.92	29.76	31.55	0.15	0.88
10th rib	16.83	17.58	0.52	14.13	20.28	<.01	0.83
Last rib	19.22	17.9	0.78	16.63	19.48	0.01	0.80
Last lumbar vertebrae	16.87	17.06	0.86	14.41	19.52	<.01	0.79
Loin eye area (cm^2)	35.18	36.14	0.51	14.87	13.22	<0.01	1.04
Carcass temperature (°C)							
1 h	31.92	31.93	0.96	30.86	32.99	<.01	0.29
6 h	9.41	9.98	0.18	8.98	10.41	<0.01	0.29
24 h	2.08	2.07	0.97	1.48	2.68	<.01	0.11
Carcass pH							
1 h	6.00	6.02	0.78	5.96	6.07	0.14	0.05
6 h	5.56	5.61	0.24	5.57	5.60	0.47	0.03
24 h	5.43	5.41	0.65	5.49	5.35	<0.01	0.02

[z] Control, consists of combined grains from a number of non-transgenic inbred lines; Bt: Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).
[y] Four pigs per pen; 32 pigs per treatment.

Table 8. Effects of corn line on *longissimus* muscle quality and composition (mean values of combined gilts and barrows) (exp. 1)

	Corn line[z]			Sex			
Item	Control	Bt	*P* value	Gilts	Barrows	*P* value	SEM
Number of pens[y]	8	8					
Longissimus muscle quality measurements							
Star probe value (kg)	5.66	5.47	0.35	5.71	5.42	0.16	0.14
Drip loss (%)	6.32	5.54	0.06	5.93	5.93	0.99	0.29
Hunter L value	52.20	51.52	0.39	51.78	51.93	0.84	0.55
Hunter a value	6.79	6.45	0.09	6.76	6.48	0.15	0.14
Hunter b value	11.71	11.31	0.02	11.79	11.23	<0.01	0.12
Hue angle (degree)	59.98	60.31	0.36	60.20	60.09	0.74	0.50
Chroma	13.57	13.05	<0.01	13.63	12.99	<0.01	0.10
Chemical composition (%)							
Protein	22.81	22.74	0.54	22.84	22.70	0.24	0.08
Fat	2.08	2.16	0.78	2.01	2.23	0.42	0.20
Moisture	73.57	73.47	0.51	73.56	73.49	0.63	0.11

[z] Control: consists of combined grains from a number of non-transgenic inbred lines; Bt: Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).
[y] Four pigs per pen; 32 pigs per treatment.

chroma value (13.63 vs. 12.99; $P < 0.01$; Table 8). No sex effects were observed for protein, fat, and moisture content of the samples (Table 8).

In exp. 2, no differences were noted for carcass characteristic parameters measured across pigs fed Bt corn compared with control corn (Table 9). Mean slaughter weights, hot carcass weights, and carcass yield were within industry norms, and were comparable among treatments. There was no corn effect on any muscle quality or composition measurement (Table 10).

The type of corn in the diet did not affect the carcass weight and carcass yield in the current experiment. This was consistent with the experiment reported by Fischer et al. (2002), Bressner et al. (2002), and Hyun et al. (2004), and was in contrast with Weber et al. (2000), in which pigs fed conventional corn were heavier during slaughter and had greater dressing percentages. Piva et al. (2001), on the other hand, found that pigs fed Bt corn were 2.8% heavier at slaughter. In agreement with most studies mentioned, no corn effects were observed for backfat thickness. Weber et al. (2000), however, found that pigs fed isogenic control corn had greater backfat depth at 10th rib and last lumbar vertebrae. No corn effects were observed for LEA, star probe and drip loss, which agreed with the studies mentioned above. No treatment effects on pH measures were observed. However, there was a 0.3 pH numerical difference between groups at 24 h. Both groups were measured simultaneously using the same probe and samples were measured randomly rather than as separate treatment groups. There was no evidence of a few samples within the Bt-fed group skewing the mean. Therefore the only explanation for this is site of sampling differences that were not great enough to cause a treatment effect, though this, too, is a weak explanation given the procedures used. In the current study, Hunter color *b* value, but neither hue angle nor chroma, was found to be significantly lower in pigs fed control corn

Table 9. Comparison of carcass characteristics of pigs fed Bt corn and control corn[x] (exp. 2)

	Corn line[y]		
Item	Control	Bt	*P* value
Slaughter weight (kg)	112.05 ± 1.54	114.06 ± 1.53	0.35
Hot carcass weight (kg)	86.95 ± 1.27	88.79 ± 1.28	0.30
Carcass yield (%)	77.51 ± 0.21	77.79 ± 0.22	0.35
Backfat (mm)			
10th rib	26.14 ± 0.19	24.04 ± 0.18	0.43
Last rib	25.39 ± 0.05	26.14 ± 0.05	0.40
Loin eye area (cm^2)	42.21 ± 0.71	43.43 ± 0..71	0.22
Carcass temperature (°C)			
1 h	38.43 ± 0.44	37.69 ± 0.45	0.24
6 h	8.98 ± 0.34	10.82 ± 0.34	<0.01
24 h	–1.92 ± 0.18	–2.02 ± 0.18	0.69
Carcass pH			
1 h	5.95 ± 0.04	5.98 ± 0.04	0.68
6 h	5.59 ± 0.03	5.64 ± 0.03	0.33
24 h	N/A[z]	N/A[z]	0.28

[x] Six barrows per pen; 60 pigs per treatment.

[y] Control: Bt 11 non-transgenic isoline; Bt: Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).

[z] 24-h pH values were 5.53 and 5.93 (SEM = 0.26) for control and Bt treatment groups, respectively. No plausible explanation for the 0.3 unit non-significant difference between treatments and the sharp increase in pH between 6- and 24-h pH readings in the Bt-fed group is available.

Table 10. Effects of corn line on *longissimus* muscle quality and composition (exp. 2)

	Corn line[z]		
Item	Control	Bt	*P* value
Number of pens[y]	10	10	–
Longissimus muscle quality measurements			
Star probe value (kg)	5.74 ± 0.11	5.55 ± 0.12	0.24
Drip loss (%)	4.27 ± 0.16	4.07 ± 0.16	0.41
Hunter L value	48.10 ± 0.42	47.95 ± 0.42	0.79
Hunter a value	6.90 ± 0.51	7.83 ± 0.52	0.21
Hunter b value	10.23 ± 0.11	10.54 ± 0.11	0.05
Hue angle (degree)	55.99 ± 0.65	55.54 ± 0.68	0.64
Chroma	12.44 ± 0.47	13.31 ± 0.50	0.22
Chemical composition (%)			
Protein	23.03 ± 0.06	23.06 ± 0.06	0.67
Fat	2.43 ± 0.16	2.59 ± 0.16	0.23
Moisture	73.02 ± 0.11	72.84 ± 0.11	0.45

[z] Control, Bt 11 non-transgenic isoline; Bt: Bt 11 (Syngenta Seeds, Inc., Golden Valley, MN).

[y] Six barrows per pen; 60 pigs per treatment.

(Table 10). These results contrast with our findings from exp. 1 and with results reported by Hyun et al. (2004), wherein no differences were observed for Minolta b* value. Results of the analysis of the longissimus muscle for protein, fat, and moisture content did not reveal any effect of corn variety, and agree with findings reported by Fischer et al. (2002) and Hyun et al. (2004).

Although other feeding trials involved feeding of transgenic corn in pigs, none of the studies reviewed used Bt "Event 11". A study in broilers involving Bt 11, however, showed that body weight, feed efficiency, and carcass measures such as dressing %, fat pad %, drums %, thighs %, wings %, and size of *pectoralis* muscle were not affected by corn source (Brake et al. 2003).

CONCLUSIONS

This study demonstrated that Bt 11 corn (containing the *cry 1Ab* gene and the *pat* gene) can be fed to growing-finishing pigs without significant differences in feed consumption, daily weight gain, and nutrient excretion. However, feed conversion was poorer in pigs fed the Bt corn. Carcass and meat quality parameters were not negatively affected by Bt 11 corn. The results suggest that feeding Bt 11 corn in pigs provides no advantages or disadvantages over conventional corn varieties used as feedstuff for swine, with respect to animal performance and consumer preferences. Based on this it can be concluded that Bt 11 corn is substantially equivalent to its non-transgenic counterpart and conventional corn varieties in terms of feeding value to swine.

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Agbios. 2003. GM crops used in animal feeds. Agriculture and Biotechnology Strategies, Merrickville, ON. [Online] Available: http://www.agbios.com/studies.php?/ [2003 Oct. 12].

Association of Official Analytical Chemists. 1990. Official methods of analysis. 15th ed. AOAC, Arlington, VA.

Association of Official Analytical Chemists. 1993. Official methods of analysis. AOAC, Arlington, VA.

Association of Official Analytical Chemists. 1995. Official methods of analysis. AOAC, Arlington, VA.

Aulrich, K., Bohme, H., Daenicke, R., Halle, I. and Flachowsky, G. 2001. Genetically modified feeds in animal nutrition 1st Communication: *Bacillus thuringiensis* (Bt) corn in poultry, pig and ruminant nutrition. Arch. Anim. Nutr. **54**: 183–195.

Brake, J., Faust, M. A. and Stein, J. 2003. Evaluation of transgenic event Bt 11 hybrid corn in broiler chickens. Poult. Sci. **82**: 551–559.

Bressner, G., Hyun, Y., Stanisiewski, E., Hartnell, G. and Ellis, M. 2002. A comparison of swine performance when fed diets containing Roundup Ready® (event NK603) or conventional corn lines. J. Anim. Sci. **80** (Suppl. 2): 128.

Fischer, R. L., Lewis, A. J., Miller, P. S., Stanisiewski, E. P. and Hartnell, G. F. 2002. Comparison of swine performance when fed diets containing Roundup Ready® Corn (event NK603), control, or conventional corn grown during 2000 in Nebraska. J. Anim. Sci. **80** (Suppl. 1): 894.

Gardner, M. A., Huff-Lonergan, E., Rowe, L. J., Schultz-Kaster, C. M. and Lonergan, S. M. 2006. Influence of harvest processes on pork loin and ham quality. J. Anim. Sci. **84**: 178–184.

Hunt, M. C. and Mancini, R. A. 2002. Guidelines for measuring pork color. Proceedings of the Third Pork Quality Improvement Symposium. 2002 Aug. 01. East Lansing, MI. American Meat Science Association, Savoy, IL.

Hyun, Y., Bressner, G. E., Ellis, M., Lewis, A. J., Fischer, R., Stanisiewski, E. P. and Hartnell, G. F. 2004. Performance of growing-finishing pigs fed diets containing Roundup Ready corn (event nk603), a nontransgenic genetically similar corn, or conventional corn lines. J. Anim. Sci. **82**: 571–580.

Jung, H. G. and Sheaffer, C. C. 2004. Influence of Bt transgenes on cell wall lignification and digestibility of maize stover for silage. Crop Sci. **44**: 1781–1789.

Koziel, M. G., Beland, G. L., Bowman, C., Carozzi, N. B., Crenshaw, R., Crossland, L., Dawson, J., Desai, N., Hill, M., Kadwell, S., Launis, K., Lewis, K., Maddox, D., McPherson, K., Meghji, M. R., Merlin, E., Rhodes, R., Warren, G. W., Wright, M. and Evola, S. V. 1993. Field performance of elite transgenic maize plants expressing an insecticidal protein derived from *Bacillus thuringiensis*. Bio/Technology **11**: 194–200.

Minolta. 1994. Precise color communication: Color control from feeling to instrumentation. Minolta Co., Ltd., Ramsey, NJ.

Moeser, A. J., Kim, I. B., van Heugten, E. and Kempen, T. A. T. G. 2002. The nutritional value of degermed, dehulled corn for pigs and its impact on the gastrointestinal tract and nutrient excretion. J. Anim Sci. **80**: 629–2638.

Mroz, Z., Jongbloed, A. W., Partanen, K. H., Vreman, K., Kemme, P. A. and Kogut, J. 2000. The effects of calcium benzoate in diets with or without organic acids on dietary buffering capacity, apparent digestibility, retention of nutrients, and manure characteristics in swine. J. Anim Sci. **78**: 2622–2632.

National Research Councli. 1998. Nutrient requirements of swine. 10th rev. ed. National Academy Press, Washington DC.

Piva, G., Morlacchini, M., Pietri, A., Piva, A. and Casadei, G. 2001. Performance of weaned piglets fed insect-protected (MON 810) or near isogenic corn. J. Anim. Sci. **79** (Suppl. 1): 441.

Rentfrow, G., Linville, M. L., Stahl, C. A., Olson, K. C. and Berg, E. P. 2004. The effects of the antioxidant lipoic acid on beef longissimus bloom time. J. Anim. Sci. **82**: 3034–3037.

Reuter, T., Aulrich, K., Berk, A. and Flachowsky, G. 2001. Nutritional evaluation of Bt-corn in pigs. J. Anim. Sci. **79** (Suppl. 1): 1073.

SAS Institute, Inc. 1990. SAS user's guide: Statistics. Version 6a ed. SAS Institute, Inc., Cary, NC.

Stanisiewski, E. P., Hartnell, G. F. and Cook, D. R. 2001. Comparison of swine performance when fed diets containing Roundup Ready® corn (GA21), parental line or conventional corn. J. Anim. Sci. **79** (Suppl. 1): 1322.

US EPA. 2000. Bt plant- pesticides, biopesticides registration action document. Scientific Advisory Panel Meeting Report, 2000 Oct. 08–20.

Vogtmann, H., Frirter, P. and Prabuck, A. 1975. A new method of determining metabolizability of energy and digestibility of fatty acids in broiler diets. Br. Poult. Sci. **16**: 531–534.

Weber, T. E., Richert, B. T., Kendall, D. C., Bowers, K. A. and Herr, C. T. 2000. Grower-finisher performance and carcass characteristics of pigs fed genetically modified "Bt" corn. Purdue University, West Lafayette, IN, 2000 Swine Day Report. [Online] Available: http://www.ansc.purdue.edu/swine/swineday/sday00/psd07-2000.html [2003 Aug. 25].