Evaluation of Transgenic Event Bt11 Hybrid Corn in Broiler Chickens[1]

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ABSTRACT A feeding study evaluated whether standard broiler diets prepared with grain derived from Syngenta Seeds NK Brand *Bacillus thuringiensis* (Bt) Corn hybrids had any adverse effects on male or female broiler chickens. Four kinds of corn grain were used in this study: (1) grain from the Bt-expressing field corn hybrid N7070Bt, (2) grain from the N7070Bt hybrid that had been sprayed with Liberty brand herbicide (glufosinate) according to manufacturer's instructions (N7070Bt + Liberty), (3) grain from standard N7070 (non-Bt isoline of N7070Bt) grain, and (4) a lot of North Carolina grown grain from the 2000 growing season (NC2000).

The amino acid balance for the four lots of corn was similar relative to their crude protein content; however, the NC2000 corn had higher protein content. Diets with the higher protein NC2000 season corn were amended with a combination of sand, ground cardboard (Solka Floc), and poultry fat so that the metabolizable energy and crude protein content of the diluted diets would be similar to that of the isoline and transgenic diets.

Growth of broilers was excellent with males being significantly heavier than females (2,497 g vs. 2,103 g) at 42 d of age. BW of live birds at 42 d was within 26 g for the three treatment groups fed corn that was from the same genetic background, i.e., the two Bt transgenic groups (N7070Bt, N7070Bt + Liberty), and the non-Bt N7070 isoline corn group, while BW for the NC2000 group was significantly lower by 93 g. There was no overall corn source effect on feed conversion ratio (FCR) among the isoline and transgenic corn sources to 42 d of age, but FCR was poorer for broilers consuming the commercial NC2000 corn. There was no overall effect of corn source on survivability to 42 d. Carcass analysis at 48 d demonstrated no differences in percentage carcass yield due to corn source among males and females.

The transgenic N7070Bt and N7070Bt + Liberty hybrid diets supported excellent broiler chicken growth with mortality and FCR that were similar to that supported by the N7070 isoline control and better than rates from the commercial NC2000 corn without significant differences among treatment groups in carcass yield. It was clear that the transgenic corn had no deleterious or unintended effects on production traits of broiler chickens in this study.

(*Key words*: transgenic corn, transgenic maize, N7070Bt corn, N7070Bt maize, broiler)

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INTRODUCTION

Agricultural biotechnology has produced a number of new varieties of crop plants with enhanced features, such as protection against common pests, tolerance to herbicides, and improved quality traits. The first commercial plantings of insect-protected field corn hybrids that utilized the "Bt" genetic modification, designated "Event 176," occurred in 1996. These corn hybrids (including those derived from Event Bt11, the subject of this study) express an insecticidal protein, Cry1Ab, similar to that produced in nature by certain subspecies of the common soil bacterium *Bacillus thuringiensis* (Bt) (Koziel et al., 1993). The Cry1Ab protein is selectively toxic to the larvae of the European Corn Borer and certain other lepidopteran larvae while nontoxic to other orders of insects as well as animals and humans. Commercial formulations of Bt have been used as topical insecticides since 1938, and such Bt-based products have been registered for use on food crops in the U.S. since 1961 [U.S. Environmental Protection Agency (EPA), 1986]. Currently, there are eight different Bt events in corn that have successfully completed the U.S. Food and Drug Administration (FDA), U.S. Department of Agriculture, and EPA review processes and are available commercially (U.S. FDA, 2002).

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[1]The use of trade names in this publication does not imply endorsement of the products mentioned nor criticism of similar products not mentioned.

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Abbreviation Key: Bt = *Bacillus thuringiensis*; FCR = feed conversion ratio; Liberty = glufosinate herbicide; N7070 = Northrup King brand corn hybrid N7070; NC2000 = North Carolina grown corn from 2000 growing season.

In addition to expressing the Cry1Ab insecticidal protein, Event Bt11 field corn also expresses a second novel protein, phosphinothricin acetyltransferase. This protein inactivates phosphinothricin, the active component in Liberty herbicide. Liberty is a postemergence herbicide registered for use on corn. Unlike most weeds present in corn fields, corn plants expressing the phosphinothricin acetyltransferase protein do not suffer damage when sprayed with Liberty herbicide when it is applied according to manufacturer's instructions.

The purpose of this study was to evaluate whether feed comprised of transgenic grain derived from Syngenta Seeds Event Bt11 (N7070Bt) hybrid field corn or N7070Bt hybrid corn that had been sprayed with Liberty herbicide (N7070Bt + Liberty) had any adverse effects on broiler chickens when compared with feed comprised of grain derived from a nontransgenic isoline. In the U.S., chickens (*Gallus domesticus*) consume large quantities of corn grain in commercial feeds. Broiler chickens, in particular, have relatively high corn consumption because conventional feeding regimens are designed to provide maximal BW gain in the shortest time. Although the transgenic protein is present in corn grain in parts per billion quantities, it was of interest to determine whether the transgenic corn grain had any unexpected effects on poultry, either as a direct effect of transgenic protein in the diet or as a result of any unintended compositional changes in the grain that may have altered its nutritional value. In order to determine whether transgenic-derived corn has an effect on broiler chicken performance, this study compared male and female broiler chickens receiving feed made with corn from a transgenic hybrid (N7070Bt and N7070Bt + Liberty) vs. feed made with the corresponding nontransgenic (N7070 isoline) version of the same hybrid and a locally (North Carolina) grown commercial lot of corn from the 2000 growing season (NC2000). A similar model has been used to study Bt corn (Halle et al., 1998; Leeson, 1998; Brake and Vlachos, 1999; Mirales et al., 2000; Gaines et al., 2001; Piva et al., 2001; Taylor et al., 2001a,b) and glyphosphate-tolerant corn (Sidhu et al., 2000; Gaines et al., 2001; Taylor et al., 2001a,b) as feeds for broiler chickens. The performance endpoints measured in this study included effects on survival, BW, feed efficiency, and carcass yield.

MATERIALS AND METHODS

Test and Control Corn

The transgenic corn grain used in this study was from both Syngenta Seeds' Event Bt11 hybrid N7070Bt and the same Bt hybrid that had been sprayed according to manufacturer's instructions with a single application of Liberty herbicide (N7070Bt + Liberty) according to manufacturer's instructions. The hybrids were field-grown in Hawaii in 2001. Following grain harvest, shelling and storage were performed using standard procedures and conditions. The presence of Cry1Ab protein in N7070Bt grain was confirmed by ELISA, and the protein was present in the grain at the expected level (~800 ng/g seed). The nontransgenic control corn grain used in this study was from Syngenta Seeds' N7070 hybrid, an isogenic (isoline) conventional hybrid, derived from the same inbred parents as the transgenic lines that was grown, processed, and stored concurrently with the transgenic hybrid under the same environmental conditions. Isolation procedures ensured that intermixing of grain genotypes did not occur. In addition, a locally grown lot of North Carolina corn from the 2000 season (NC2000) was used for comparison purposes. The NC2000 season corn was in storage at the time of the experiment and was known to be of adequate quality to support good broiler chicken growth.

Experimental Design

The experimental design consisted of diets made from four types of corn (transgenic N7070Bt and N7070Bt + Liberty, nontransgenic isoline N7070, and locally grown NC2000 corn) fed to two sexes of birds housed within four location blocks of the growing facility with eight replicates for each two-way corn source × sex interaction. Pens were assigned in a randomized complete block design to compensate for known location effects in the growing facility.

Broiler chicks were hatched from commercial hatching eggs incubated at the site. The broiler breeder parent stock was a commercial strain of Ross males and feather-sexable females. Broiler chicks were feather-sexed and very large and small chicks were excluded. Furthermore, any chicks exhibiting obvious abnormalities were not used in the study. A total of 1,600 birds were randomly distributed into 64 pens of a curtain-sided house at 1 d of age so that pens contained 25 birds of the same sex. Birds were identified by neck tag indicating animal number.

Corn Analyses

Samples of each of the four lots of corn were forwarded to independent laboratories using standard methods (AOAC, 1990, 1993) for proximate analyses, amino acid analyses, and mycotoxin screening. Results are shown in Table 1 and are reported as the percentage by weight on an as-is basis (i.e., not as a percent of the dry weight). Amino acid analyses showed very similar amino acid patterns for samples of transgenic (N7070Bt and N7070Bt + Liberty), isoline (N7070), and NC2000 corn and confirmed differences in crude protein and moisture between the N7070-based lots and the NC2000 corn. Initial routine mycotoxin determinations showed extremely low contamination for both aflatoxins and deoxynivalenol (vomitoxin) (Table 1) in all corn samples. There was some evidence of fumonisin in all of the corn samples. However, the levels of mycotoxins found in the corn were not excessive by commercially accepted standards. By comparison, feeding of diets containing deoxynivalenol at levels approaching 500 ppb is frequent in commercial broiler practice without obvious effect.

TABLE 1. Analyses of corn samples[1]

Analyses[2]	Corn source: N7070 Isoline	N7070Bt	N7070Bt + Liberty	NC2000
Proximate analyses,[3] %				
Moisture	10.52	10.94	10.73	12.76
Fat	3.39	3.21	3.03	3.53
Protein	7.79	7.60	7.71	8.69
Fiber	1.30	1.20	1.30	1.93
Ash	1.27	1.18	1.27	1.22
Amino acids,[4] %				
Taurine	0.15	0.19	0.18	0.17
Hydroxyproline	0.02	0.02	0.02	0.02
Aspartic acid	0.53	0.54	0.58	0.56
Threonine	0.26	0.26	0.27	0.29
Serine	0.31	0.30	0.33	0.35
Glutamic acid	1.46	1.44	1.57	1.73
Proline	0.70	0.68	0.73	0.81
Lanthionine	0.00	0.00	0.00	0.00
Glycine	0.30	0.30	0.31	0.35
Alanine	0.57	0.57	0.62	0.67
Cysteine	0.19	0.18	0.20	0.21
Valine	0.38	0.38	0.39	0.45
Methionine	0.15	0.15	0.16	0.19
Isoleucine	0.26	0.25	0.27	0.31
Leucine	0.90	0.86	0.93	1.11
Tyrosine	0.23	0.22	0.24	0.26
Phenylalanine	0.37	0.36	0.39	0.45
Hydroxylysine	0.00	0.00	0.00	0.00
Histidine	0.22	0.22	0.24	0.27
Ornithine	0.01	0.01	0.01	0.01
Lysine	0.26	0.25	0.27	0.27
Arginine	0.37	0.36	0.38	0.44
Tryptophan	0.05	0.06	0.06	0.07
Total	7.69	7.60	8.15	8.99
Mycotoxin analyses[5]				
Aflatoxins, ppb	ND[6]	ND	ND	ND
Deoxynivalenol, ppb	ND	ND	ND	ND
Fumonisin B_1, ppm	20.6	9.9	15.6	8.8

[1]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

[2]Reported on an as-is basis.

[3]Woodson-Tenent Laboratories, Goldston, NC.

[4]Experiment Station Chemical Laboratory, Univ. of Missouri, Columbia, MO.

[5]Trilogy Analytical Laboratory, Inc., Washington, MO.

[6]Not detected.

Diet Formulation

Based on the initial proximate analyses (Table 1), grain from the three Syngenta Seed's N7070 series hybrids were assumed to have the same nutritive value. To compensate for the relatively large difference in percentage crude protein between the NC2000 and N7070-based corn sources, an inert nonnutritive filler composed of Solka Floc 40 (cardboard) and sand, formulated to the same density as ground corn, was added to volume. Furthermore, an appropriate quantity of additional poultry fat was added as a portion of the filler to compensate for the ME lost due to removal of a portion of the corn and replacement with the nonnutritive filler. Diet formulation was on the basis of the N7070 isoline corn with filler added as described above for the respective diets made from the NC2000 corn (Table 2). The N7070 basal diet formulation reflected commercial practice at the time of the study. Nutrient levels met or exceeded the minimum nutritional requirements for broiler chickens as set by the National Research Council (1994). Diets were pelleted in a small commercial-style pellet mill immediately after mixing. Pelleted starter feed was crumbled.

Access to Feed and Water

Birds were provided continuous access to feed and water for ad libitum consumption from two tube feeders and one automatic bell-type waterer in each pen. Supplemental waterers as well as supplemental feeder flats were used during the first week to ensure unlimited access to feed and water. The feeders were manually agitated as needed to maintain the flow of feed from the tube into the feeder pan from which the birds fed. Birds had access to 1.13 kg starter diet per bird during the first 21 d of the study. This was followed by the grower diet, which was

TABLE 2. Diets and calculated analyses by corn source[1]

Ingredient	Starter diets				Grower diets				Finisher diets			
	N7070 Isoline	N7070Bt	N7070Bt + Liberty	NC2000	N7070 Isoline	N7070Bt	N7070Bt + Liberty	NC2000	N7070 Isoline	N7070Bt	N7070Bt + Liberty	NC2000
	(% by weight)											
Corn	48.19	48.19	48.19	47.79	56.88	56.88	56.88	51.54	63.56	63.56	63.56	57.56
Soybean meal	41.05	41.05	41.05	41.07	33.64	33.64	33.64	33.65	28.33	28.33	28.33	28.33
Limestone (calcium carbonate)	1.10	1.10	1.10	1.09	1.12	1.12	1.12	1.13	1.02	1.02	1.02	1.02
Dicalcium phosphate	1.72	1.72	1.72	1.71	1.77	1.77	1.77	1.77	1.53	1.53	1.53	1.53
Poultry fat	6.54	6.54	6.54	6.65	5.35	5.35	5.35	7.37	4.22	4.22	4.22	6.51
DL-Methionine	0.24	0.24	0.24	0.25	0.08	0.08	0.08	0.08	0.03	0.03	0.03	0.03
Trace mineral premix	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Salt (NaCl)	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.33	0.33	0.33	0.33
Coccidiostat (Monensin)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Selenium premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sand filler	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.82	0.03	0.03	0.03	0.95
Solka Floc filler[2]	0.00	0.00	0.00	0.18	0.00	0.00	0.00	2.48	0.04	0.04	0.04	2.83
Sodium bicarbonate	—	—	—	—	—	—	—	—	0.18	0.18	0.18	0.18
Ascorbic acid	—	—	—	—	—	—	—	—	0.11	0.11	0.11	0.11
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
Calculated analyses[3]												
Metabolizable energy, kcal/g	3.20	—	—	—	3.20	—	—	—	3.20	—	—	—
Crude protein, %	23.47	—	—	—	20.50	—	—	—	18.50	—	—	—
Lysine, %	1.35	—	—	—	1.15	—	—	—	1.00	—	—	—
Methionine + cystine, %	0.99	—	—	—	0.75	—	—	—	0.65	—	—	—
Threonine, %	0.90	—	—	—	0.78	—	—	—	0.71	—	—	—

[1]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

[2]Fibre Sales and Development Corporation, Checkerboard Square, St. Louis, MO.

[3]Based on analytical values used for formulation and National Research Council (1994) reference values. All formulas were derived from the base formulation with N7070. The NC2000 diet was developed by reduction of crude protein by addition of a sand and Solka Floc filler that had the same density as corn and poultry fat to compensate for metabolizable energy lost with the corn that was removed.

added to any starter diet that remained in the feeders at 21 d. At 35 d, remaining grower diet was weighed and discarded and a finisher diet was added to the feeders. Feed was available for ad libitum consumption except at 42 and 43 d of the experiment when access to feed was limited to control heat-stress-related mortality. Also, access to feed was discontinued approximately 12 h before slaughter on the night of the 47th d of the experiment.

Housing and Environmental Conditions

Birds were housed in 1.2- × 3.7-m pens with pine shavings as litter. House temperature was 32°C for the first week of the experiment and decreased gradually until ambient summer conditions were reached. Temperature was maintained using thermostatically controlled liquid propane (LP) gas brooders and circulating fans. The house was ventilated using stirring fans and manually operated curtains. The birds received 23 h of incandescent light per day until 7 d of age, 21 h of light from 8 d to 28 d of age, 20 h of light from 29 to 35 d of age, and 19 h of light for the remainder of the experiment.

Heat Stress Incident

At 41 d of the experiment, there was a sudden and extreme increase in ambient temperature and humidity. The heat index exceeded 43°C during the afternoon, and birds began to die. All mortalities were weighed as quickly as possible, and on the morning of 42 d, the decision was made to terminate the growth performance portion of the experiment by weighing all live birds and total feed consumed. For completeness, BW of live and dead birds are presented; however, group differences were minor and unimportant. Access to feed was limited on 42 and 43 d of the experiment to allow broilers to lose body heat. After the ambient heat stress subsided, the broilers were returned to full feed for 44 d through 47 d of the experiment prior to processing.

Data Collection

Total pen weight data were collected at hatch (1 d), 21 d, 35 d, and 42 d of age. All birds that died were weighed as soon as possible after death. At the latter three time points, feed consumption per pen was determined for calculating the adjusted FCR.[3] At 48 d after recovery from the heat stress, a random sample of two birds from each pen was processed in order to determine carcass (meat) yield. These birds were stunned, killed by exsanguination, scalded, picked, eviscerated, and deboned as previously reported (Brake et al., 1993).

[3]Adjusted feed conversion ratio (calculated for each pen) = total feed consumed/total BW of surviving birds + total terminal BW of birds that died.

Statistical Analyses

The data for BW, FCR, and survival were analyzed to determine statistical differences for corn diets and sex. Statistical analyses were performed using the general linear model (GLM) procedure of SAS Institute (1999) with sex and corn source as independent variables in a two-way analysis of variance within a randomized complete block design, with random error (between-pen variation) as the error term. Individual broiler carcass data on gross and adjusted to BW (%) bases were analyzed for effects due to corn source within sex using a one-way analysis of variance, as carcass effects due to sex are well known. Statements of statistical significance were based upon $P < 0.05$.

RESULTS AND DISCUSSION

Diet Analyses

The percentages of crude protein, moisture, fat, fiber, and ash of the formulated diets, as determined by proximate analyses, are shown in Table 3. Variability was within the normally expected range. Percentage dietary fat varied somewhat, and the NC2000 diets appeared to contain slightly more fat overall as expected. This was probably a function of the additional poultry fat filler used to compensate for the ME lost from diluting the corn portion of the diets. These differences were not substantial but could have small effects on BW and FCR. The percentages of fiber and ash were obviously higher for the NC2000 corn only in the finisher diet. These observations reflect the higher inclusion rate of sand (ash) and Solka Floc (fiber) in the NC2000 finisher diet.

Body Weight Data

The effect of corn source and sex on BW is shown in Table 4. There were no significant interactions between corn source and sex at any age. The results showed that at hatch and placement (1 d) there were no differences in the BW of all chicks placed in the study. As expected, by 21 d of age, sex effects became evident with the males weighing significantly more than the females. These effects were also observed at 35 and 42 d. There were significant BW differences due to corn source at 21, 35, and 42 d of age for live birds; the birds fed the NC2000 diets exhibited the lowest BW throughout the experiment. This likely was due to an interaction between the climatic conditions and the diet formulation that affected feed intake (as discussed below) and, consequently, reduced growth rates for NC2000 groups. Birds fed the isoline N7070 and transgenic N7070Bt and N7070Bt + Liberty corn source diets performed in a statistically similar manner at all ages. For the 42 d measure, separate results for live and dead birds are presented to account for birds that died as a result of the heat stress at 41 and 42 d (Table 4). However, relatively little difference between diet groups in BW occurred for the live and dead birds.

TABLE 3. Analyses of formulated diet samples

Diet analyses[1]	Corn source[2] N7070 Isoline	N7070Bt	N7070Bt + Liberty	NC2000
Percentage crude protein				
Starter	24.10	24.62	25.43	23.49
Grower	23.24	22.20	22.72	25.20
Finisher	17.92	19.44	18.97	20.32
Percentage moisture				
Starter	10.69	11.35	11.27	11.61
Grower	11.16	11.32	11.35	11.59
Finisher	10.99	11.49	11.05	11.39
Percentage fat				
Starter	8.35	7.87	7.90	8.06
Grower	7.24	7.43	6.80	7.64
Finisher	6.51	6.24	6.08	8.22
Percentage fiber				
Starter	2.10	2.40	2.00	1.90
Grower	1.90	2.10	2.00	2.00
Finisher	2.50	2.60	2.40	2.80
Percentage ash				
Starter	5.72	5.86	5.56	5.59
Grower	5.73	5.18	5.61	5.62
Finisher	4.67	4.69	4.86	5.21

[1]Analyses performed by Woodson-Tenent Laboratories, Goldston, NC, on an as-is basis.

[2]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

There were no sex × corn source interactions; males typically grew faster than females. Piva et al. (2001) reported that birds fed diets containing Bt corn were slightly heavier at finish than birds fed the non-Bt isoline control hybrid, while results from other studies indicated no impact of Bt hybrids for final BW and BW gain in broilers (Halle et al., 1998; Brake and Vlachos, 1999; Mirales et al., 2000; Taylor et al., 2001a,b).

Feed Conversion

The effect of corn source and sex on FCR during individual feeding periods and cumulatively are shown in Table 5. There were no significant interactions between corn source and sex at any age. It is well established that males exhibit better FCR than do females, as found in this study (Table 5). Corn source had a significant effect on FCR during the starter period (0 to 21 d), finisher period (35 to 42 d), and cumulatively (0 to 42 d) due to poorer performance from broilers fed the NC2000 diets. Groups fed the isoline N7070 and transgenic N7070Bt and N7070Bt + Liberty corns performed in a statistically similar manner. There was no interaction of sex × corn source for FCR.

Although efforts were made in this study to adjust diets for observed small differences in corn source (NC2000

TABLE 4. The effect of corn source and sex on BW of broiler chickens[1,2]

Corn source[3]	Sex	BW at hatch Mean	BW at hatch SEM	BW at 21 d Mean	BW at 21 d SEM	BW at 35 d Mean	BW at 35 d SEM	BW at 42 d (live) Mean	BW at 42 d (live) SEM	BW at 42 d (dead) Mean	BW at 42 d (dead) SEM	BW at 42 d (live + dead) Mean	BW at 42 d (live + dead) SEM
		(g)											
N7070 Isoline		37.8	0.18	824.4[a]	10.81	1,841.8[a]	35.13	2,329.0[a]	52.60	2,246.9	97.59	2,319.6[a]	51.19
N7070Bt		37.7	0.22	809.6[a]	12.58	1,816.7[ab]	36.68	2,303.7[a]	54.14	2,213.7	73.58	2,285.2[ab]	52.23
N7070Bt + Liberty		37.5	0.29	809.0[a]	9.91	1,820.6[ab]	35.09	2,319.7[a]	51.17	2,239.6	47.62	2,309.8[a]	50.26
NC 2000		38.0	0.24	773.5[b]	10.74	1,790.0[b]	38.53	2,210.5[b]	59.00	2,224.5	74.13	2,208.7[b]	58.76
P-value effect of corn source		0.50		0.0001		0.02		0.003		0.99		0.02	
	Male	37.9	0.17	841.2[a]	5.56	1,951.5[a]	9.02	2,496.5[a]	16.41	2,411.8[a]	32.02	2,479.9[a]	17.15
	Female	37.5	0.15	767.1[b]	4.62	1,683.1[b]	7.77	2,102.9[b]	11.25	2,046.1[b]	44.98	2,098.7[b]	11.11
P-value effect of sex		0.11		0.0001		0.0001		0.0001		0.0001		0.0001	

[a,b]Means with different superscripts differ significantly ($P \leq 0.05$).

[1]Starter, grower, and finisher diets were used to 21, 35, and 42 d of age, respectively.

[2]There were eight replicate pens of 25 birds each for each interaction mean except for the NC 2000 treatment after 35 d for which six replicate pens were used.

[3]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

TABLE 5. The effect of corn source and sex on adjusted feed conversion ratio (FCR) of broiler chickens[1,2]

Corn source[3]	Sex	Starter FCR 0–21 d		Grower FCR 21–35 d		Finisher FCR 35–42 d		Cumulative FCR 0–35 d		Cumulative FCR 0–42 d	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
		(g:g)									
N7070 Isoline		1.32[b]	0.01	1.81	0.01	3.19[b]	0.14	1.60	0.01	1.92[b]	0.02
N7070Bt		1.33[b]	0.01	1.83	0.04	3.20[b]	0.13	1.61	0.02	1.94[b]	0.03
N7070Bt + Liberty		1.33[b]	0.00	1.77	0.03	3.26[b]	0.14	1.58	0.01	1.93[b]	0.03
NC 2000		1.37[a]	0.01	1.79	0.01	3.73[a]	0.24	1.61	0.01	2.01[a]	0.03
P-value effect of corn source		0.0002		0.30		0.02		0.26		0.005	
	Male	1.33[b]	0.01	1.76[b]	0.01	2.84[b]	0.06	1.58[b]	0.01	1.84[b]	0.01
	Female	1.35[a]	0.00	1.84[a]	0.02	3.79[a]	0.10	1.62[a]	0.01	2.05[a]	0.01
P-value effect of sex		0.03		0.005		0.0001		0.008		0.0001	

[a,b]Means that possess different superscripts differ significantly ($P \leq 0.05$).

[1]Starter, grower, and finisher diets were used to 21, 35, and 42 d of age, respectively.

[2]There were eight replicate pens of 25 birds each for each interaction mean except for the NC 2000 treatment after 35 d for which six replicate pens were used. Adjusted FCR includes the BW of birds that died during each diet period in the calculation.

[3]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

vs. the N7070-based isoline and transgenic corns) with respect to total protein (Table 2), it cannot be stated that the diets were identical (Table 3). It appeared that the NC2000 diets were not consumed as well as the N7070 series diets. It was possible that the NC2000 diet was of poorer pellet quality that would decrease feed intake, or that the NC2000 diet was more hygroscopic in the humid summer weather experienced at the time of the study, or both. These factors could affect the flow of the feed from the tube into the feeder pan, in spite of daily efforts to maintain equal feed flow by physical agitation of the feeders. Obvious evidence of this latter factor was found in two pens late in the finisher period, and these pens were deleted from the statistical analysis for the final time period and cumulatively. Therefore, the differences in FCR cannot necessarily be attributed to the corn source per se, but it is important to note that these data fail to show an obvious deleterious effect associated with the diets made from transgenic corn when compared to diets made from isoline and commercial corn. In a previous study with Event 176 Bt corn, Brake and Vlachos (1999) reported an advantage in FCR for birds fed Bt vs. non-Bt control hybrids. These authors suggested that the performance advantage for broilers fed Bt containing diets may have resulted due to lower mycotoxin levels for this corn. Other workers have identified no differences in FCR

TABLE 6. The effect of corn source and sex on survival of broiler chickens[1,2,3]

Corn source[4]	Sex	Starter deaths 0–21 d		Grower deaths 21–35 d		Finisher deaths 35–42 d		Cumulative deaths 0–35 d		Cumulative deaths 0–42 d	
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
		(%)									
N7070 Isoline		1.50	0.62	0.75	0.40	14.00	2.76	2.25	0.63	16.25	2.59
N7070Bt		0.50	0.34	0.25	0.25	18.25	4.87	0.75	0.40	19.00	4.95
N7070Bt + Liberty		1.25	0.48	0.75	0.40	14.25	3.41	2.00	0.63	16.25	3.43
NC 2000		1.75	0.63	0.50	0.34	6.57	1.81	2.25	0.73	9.14	2.39
P-value effect for corn source		0.39		0.69		0.09		0.22		0.23	
	Male	1.25	0.33	0.50	0.24	20.27[a]	2.98	1.75	0.40	22.13[a]	2.96
	Female	1.25	0.42	0.63	0.26	7.13[b]	1.24	1.88	0.47	9.00[b]	1.37
P-value effect for sex		1.00		0.72		0.0002		0.83		0.0003	
N7070 Isoline	Male	0.50	0.50	0.50	0.50	21.00	3.91	1.00[bc]	0.65	22.00	3.85
N7070 Isoline	Female	2.50	1.05	1.00	0.65	7.00	1.81	3.50[a]	0.91	10.50	2.13
N7070Bt	Male	1.00	0.65	0.50	0.50	27.50	7.84	1.50[abc]	0.73	29.00	7.77
N7070Bt	Female	0.00	0.00	0.00	0.00	9.00	3.98	0.00[c]	0.00	9.00	3.98
N7070Bt + Liberty	Male	1.50	0.73	0.00	0.00	20.00	6.05	1.50[abc]	0.73	21.50	6.18
N7070Bt + Liberty	Female	1.00	0.65	1.50	0.73	8.50	1.92	2.50[ab]	1.05	11.00	2.10
NC 2000	Male	2.00	0.76	1.00	0.65	10.00	3.39	3.00[ab]	1.00	14.00	3.97
NC 2000	Female	1.50	1.05	0.00	0.00	4.00	1.51	1.50[abc]	1.05	5.50	2.38
P-value effect for corn source × sex		0.20		0.06		0.54		0.04		0.58	

[a–c]Means that possess different superscripts differ significantly ($P \leq 0.05$).

[1]Starter, grower, and finisher diets were used to 21, 35, and 42 d of age, respectively.

[2]There were eight replicate pens of 25 birds each for each interaction mean.

[3]Survival expressed as percentage (%) deaths.

[4]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

TABLE 7. The effect of corn source on percentage carcass yield of male broiler chickens at 48 d of age[1,2]

	BW (g)		Dressed carcass[4] (%)		Fat pad (%)		Drums (%)		Thighs (%)		Wings (%)		Pectoralis major (%)		Pectoralis minor (%)	
Corn source[3]	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
N7070 Isoline	2,922.5	63.78	72.99	0.37	1.21	0.07	11.03	0.12	13.40	0.23	7.80	0.06	14.95	0.32	3.90	0.05
N7070Bt	2,945.4	50.89	73.29	0.30	1.56	0.09	10.71	0.18	13.49	0.18	7.90	0.12	14.24	0.27	3.79	0.08
N7070Bt + Liberty	2,876.3	60.39	73.14	0.34	1.62	0.19	10.89	0.19	13.34	0.19	7.76	0.09	14.60	0.33	3.81	0.07
NC 2000	2,990.3	81.85	72.38	0.42	1.21	0.16	10.97	0.16	13.35	0.28	7.60	0.10	14.71	0.21	3.89	0.06
P-value	0.66		0.30		0.06		0.53		0.96		0.17		0.37		0.48	

[1]Starter, grower, and finisher diets were used to 21, 35, and 42 d of age, respectively.

[2]There were 16 birds processed within each corn source and sex.

[3]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

[4]Fresh, unchilled carcass from which the head, neck, feet, feathers, viscera and blood have been removed.

for broilers fed diets containing Bt and non-Bt isoline corn (Halle et al., 1998; Mirales et al., 2000; Piva et al., 2001; Taylor et al., 2001a,b). Gaines et al. (2001) reported finding differences in average daily feed intake and gain/feed (inverse of FCR) for broiler chickens fed diets containing corn from different genetic backgrounds, but no differences in these measures for groups fed Bt and non-Bt isoline hybrids with the same genetic background.

Survival

There were no significant differences in percentage survivors for birds that received the two transgenic corn diets and those that received the N7070 isoline and commercial NC2000 corn diets on an overall basis at any age (Table 6). However, there were significant differences due to sex, with males exhibiting higher mortality during the finisher phase (35 to 42 d) and cumulatively (0 to 42 d). This should be expected in extremely hot weather conditions as males are well known to be more susceptible to heat stress. There was a significant interaction of sex and corn source for the combined starter-grower periods (0 to 35 d) due to some erratic mortality during the grower period (21 to 35 d) that was not evident on a cumulative basis. This interaction did not follow any logical or explainable pattern and probably represents chance occurrences. Similarly, Brake and Vlachos (1999) identified no differences in survival for broilers fed Bt or control hybrids.

Carcass and Parts Yield

The yield of carcass parts as a percentage of live BW for males and females at 48 d of age are shown in Tables 7 and 8, respectively. There was no effect of corn source, which was consistent with results reported by Taylor et al. (2001a) for broilers fed Bt and non-Bt corn. However, Brake and Vlachos (1999) hypothesized that lower mycotoxin levels for Bt corn in their experiment may have explained the slight advantage in yield of pectoralis minor for birds fed diets containing Bt vs. isoline control hybrids.

Our study was carried out to determine whether diets prepared with transgenic corn would have any adverse effects on performance of broiler chickens when compared to diets prepared with nontransgenic (isogenic) control and commercial corn. Only minor differences were found due to corn source; performance was poorer for birds fed the commercial NC2000 corn diets. The transgenic N7070Bt and N7070Bt + Liberty hybrid diets supported broiler BW and FCR that was equivalent to growth from the N7070 isoline corn and better than that from the NC2000 corn without significant differences in carcass yield. While it is not clear whether the small differences in performance for NC2000 diets was attributable to the commercial corn per se or due to possible slight differences in overall composition of the formulated diets,

TABLE 8. The effect of corn source on percentage carcass yield of female broiler chickens at 48 d of age[1,2]

	BW (g)		Dressed carcass[4] (%)		Fat pad (%)		Drums (%)		Thighs (%)		Wings (%)		Pectoralis major (%)		Pectoralis minor (%)	
Corn source[3]	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
N7070 Isoline	2,512.4	45.55	72.77	0.97	1.51	0.10	10.11	0.25	12.71	0.28	7.59	0.16	15.61	0.29	4.15	0.07
N7070Bt	2,423.1	70.41	73.00	0.40	1.86	0.18	10.33	0.14	12.70	0.17	7.99	0.10	15.30	0.30	4.17	0.10
N7070Bt + Liberty	2,387.9	36.49	73.30	0.36	1.77	0.12	10.33	0.12	12.81	0.14	7.86	0.08	15.28	0.25	4.19	0.06
NC 2000	2,393.4	36.89	73.09	0.28	1.66	0.06	10.36	0.12	12.98	0.14	7.73	0.09	15.35	0.22	4.13	0.07
P-value	0.26		0.93		0.24		0.70		0.72		0.07		0.80		0.94	

[1]Starter, grower, and finisher diets were used to 21, 35, and 42 d of age, respectively.

[2]There were 16 birds processed within each corn source and sex.

[3]N7070 = Northrup King brand corn hybrid N7070; Bt = *Bacillus thuringiensis*; Liberty = glufosinate herbicide; NC2000 = North Carolina grown corn from 2000 growing season.

[4]Fresh, unchilled carcass from which the head, neck, feet, feathers, viscera and blood have been removed.

it was clear that the transgenic corn had no deleterious effects in this study.

REFERENCES

AOAC. 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

AOAC. 1993. Changes in Official Methods of Analysis. 4th Supplement to the 15th ed. Association of Official Analytical Chemists, Arlington, VA.

Brake, J., G. B. Havenstein, S. E. Scheideler, P. R. Ferket, and D. V. Rives. 1993. Relationship of sex, age, and body weight to broiler carcass yield and offal production. Poult. Sci. 72:1137–1145.

Brake, J., and D. Vlachos. 1999. Evaluation of transgenic event 176 "Bt" corn in broiler chickens. Poult. Sci. 77:648–653.

Gaines, A. M., G. L. Allee, and B. W. Ratliff. 2001. Nutritional evaluation of Bt (MON810) and Roundup Ready® corn compared with commercial hybrids in broilers. Poult. Sci. 80(Suppl. 1):51. (Abstr.)

Halle, I., K. Aulrich, and G. Flachowsky. 1998. Einsatz von maiskörnen der sorte Cesar und des gentechnisch veränderten Bt-Hybriden in der broilermast. Pages 265–267 in Proceedings of the 5th Tagung. Schweine-und Geflügelernährung, Wittenberg, Germany.

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

Leeson, S. 1998. The effect of corn hybrid CBH351 on the growth of male broiler chickens. http:www.epa.gov/pesticides/biopesticides/cry9c/der- 44734306a.html. Accessed: Sept. 2002.

Mirales, Jr., A., S. Kim, R. Thompson, and B. Amundsen. 2000. GMO (Bt) corn is similar in composition and nutrient availability to broilers as non-GMO corn. Poult. Sci. 79(Suppl. 1):65–66. (Abstr.)

National Research Council. 1994. Nutrient Requirements of Poultry, 9th rev. ed. National Academy Press, Washington, DC.

Piva, G., M. Morlacchini, A. Pietri, F. Rossi, and A. Prandini. 2001. Growth performance of broilers fed insect-protected (MON810) or near isogenic control corn. Poult. Sci. 80(Suppl. 1):320. (Abstr.)

SAS Institute. 1999. SAS/STAT User's Guide. Version 8. SAS Institute Inc., Cary, NC.

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.

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

Taylor, M. L., G. F. Hartnell, M. A. Nemeth, B. George, and J. D. Astwood. 2001b. Comparison of broiler performance when fed diets containing Roundup Ready® corn event NK603, parental line, or commercial corn. Poult. Sci. 80(Suppl. 1):320. (Abstr.)

U.S. Environmental Protection Agency. 1986. Pesticide Fact Sheet No. 93. *Bacillus thuringiensis*, U.S. Environmental Protection Agency, Washington, DC.

U.S. Food and Drug Administration (FDA). 2002. List of completed consultations on bioengineered foods. Center for Food Safety and Applied Nutrition. Office of Food Additive Safety. March. http://www.cfsan.fda.gov/~lrd/biocon.html. Accessed June 2002.