J. Dairy Sci. 84(E. Suppl.):E9-E18

Livestock Performance: Feeding Biotech Crops

J. H. Clark and I. R. Ipharraguerre

Department of Animal Sciences
University of Illinois, Urbana 61801

ABSTRACT

To date, genetically enhanced plants in the marketplace that are used as feeds for livestock are based on producing insecticidal compounds or developing herbicide tolerance. Corn grain, whole plant green chop corn, corn silage, corn residue, soybeans, and soybean meal from the current genetically enhanced plants have been fed to chickens, sheep, beef cattle, and dairy cows and compared with feeds produced from isolines of nongenetically enhanced plants. Results from 23 research trials indicate that genetically enhanced corn and soybeans that are currently available in the marketplace are substantially equivalent in composition, are similar in digestibility, and have a similar feeding value for livestock.
(Key words: genetically enhanced crops, biotech crops, livestock performance)
Abbreviation key: ADG = average daily gain.

INTRODUCTION

"Biotechnology refers generally to the application of a wide range of scientific techniques to the modification and improvement of plants, animals, and microorganisms that are of economic importance. Agricultural biotechnology is that area of biotechnology involving applications to agriculture. In the broadest sense, traditional biotechnology has been used for thousands of years, since the advent of the first agricultural practices, for the improvement of plants, animals, and microorganisms" (Persley and Siedow, 1999). Genetic engineering is one form of biotechnology just as is the traditional selection and breeding of plants and animals that possess desirable genetic traits. Plants that supply feeds for livestock have improved over the years because new plant varieties were developed using traditional techniques of biotechnology. Crops to supply feed for livestock produced through genetic enhancement are emerging from research and development to the marketplace because scientists have developed techniques to transfer specific genes from one organism to another, allowing the expression of desirable traits in the recipient organism. This genetic enhancement approach allows for a quicker and more specific selection of traits or compounds produced by the organism. These organisms are referred to as genetically modified or genetically enhanced organisms. When used with plants, this new technology is a more selective improvement process that promises to enhance productivity while using more sustainable and environmentally sound approaches for producing livestock feeds (Hartnell and Fuchs, 1999).

Received August 1, 2000.
Accepted October 4, 2000
Corresponding author: J. H. Clark; e-mail: j-clark6@uiuc.edu.

To date, genetically enhanced plants that have reached the marketplace are based on producing insecticidal compounds or developing herbicide tolerance. Plants that are genetically enhanced to contain a gene from *Bacillus thuringiensis* (Bt), a soil bacterium, produces protein that affects only a narrow range of pests but kills the European corn borer (*Ostrinia nubilalis*). The Bt insecticidal proteins have been successfully used commercially since the early 1960s and have a history of being safe when their directions for application are followed. The European corn borer is a common and economically destructive pest of corn that costs corn producers in the United States and Canada more than one billion dollars each year (Ostlie et al., 1997). Herbicide-tolerant plants that are currently being marketed are produced by the stable insertion of a gene that expresses a glyphosate-tolerant, modified plant 5-enolpyruvylshikimate-3-phosphate synthase protein in the receptor plant (LeBrun et al., 1997) rendering it tolerant to the herbicide glyphosate, which allows for increased weed control.

Corn grain, whole plant green chop corn, corn silage, corn residue, soybeans, and soybean meal from the current genetically enhanced plants have been fed to livestock and compared with feeds produced from isolines of nongenetically enhanced plants. Chickens, sheep, beef cattle, and dairy cows have been used in these experiments. The purposes of these experiments were to compare genetically enhanced and nongenetically enhanced isolines of corn and soybeans for nutritional equivalence and digestibility, and to determine production and health of livestock fed these feeds. Composition, digestibility, and livestock production responses have been measured in the experiments that have been completed to date. The objective of this paper is to review the results obtained from these experiments.

Bt CORN

Fungi Growth Reduced by Bt Corn

The Bt corn contains genes from *Bacillus thuringiensis* that express protein that affects only a narrow range of pests but kills the European corn borer, a common pest in corn fields. Corn borers reduce the quality and yield of corn and damage the plant tissue, resulting in increased opportunity for fungal growth. The fungi can release mycotoxins that can be toxic to both animals and humans. Some species of *Fusarium* fungi produce fumonisin, a dangerous toxin that can kill horses and pigs and cause esophageal cancer in humans. Eliminating the corn borer from corn reduces growth of the fungi from the corn plant (Munkvold et al., 1997, 1999) and increases the quality and yield of corn. Because the Bt proteins produced in the genetically enhanced corn plant serve as insecticides, they kill the corn borers before they do much damage to the corn plant, and the opportunity for fungal growth is decreased. Therefore, in addition to protecting the corn plant from the corn borer, genetic enhancement to produce Bt corn that is resistant to this pest may improve the safety of corn for animal and human consumption by reducing fungal growth.

Table 1. Energy content and digestibilities of OM and protein in non-Bt and Bt corn grain determined using laying hens.[1]

Item	Corn	
	Non-Bt (Cesar)	Bt
Metabolizable energy, kJ/g	11.07	11.05
Digestibility, %		
OM	76.9	77.2
Protein	89.2	90.0
BW, g		
Initial	1586	1568
Final	1585	1577

[1]Aulrich et al. (1998).

Table 2. Body weight gain, feed intake, feed efficiency, and protein digestibility determined using broiler chicks fed non-Bt (Cesar) and Bt corn grain.[1]

Item	Corn	
	Non-Bt (Cesar)	Bt
Body weight, g		
Initial	41	43
Final	1673	1588
Gain	1632	1545
Feed intake, g	2627	2522
Feed/gain, g/g	1.61	1.63
Protein digestibility, %	81.8	83.7

[1]Halle et al. (1998).

Table 3. Nutrient content of corn grain.[1]

Item	Corn	
	Non-Bt (G4665)	Bt[2] (5506BTX)
Proximate analysis, %		
Moisture	11.62	12.13
Fat	3.00	3.19
Protein	8.87	8.43
Fiber	2.10	2.20
Ash	0.93	1.02
Amino acids, %		
Taurine	0.12	0.12
Hydroxyproline	0.02	0.02
Asp	0.55	0.55
Thr	0.31	0.31
Ser	0.40	0.40
Glu	1.66	1.65
Pro	0.85	0.84
Gly	0.33	0.34
Ala	0.70	0.69
Cys	0.23	0.23
Val	0.41	0.42
Met	0.21	0.21
Ile	0.29	0.29
Leu	1.15	1.14
Tyr	0.27	0.29
Phe	0.45	0.45
His	0.27	0.27
Orn	0.02	0.02
Lys	0.25	0.26
Arg	0.38	0.39
Trp	0.06	0.05

[1]Brake and Vlachos (1998).

[2]From Event 176. The event was a single insertion of transgenic DNA into the plant genome.

Chickens

Three research trials have been conducted in which Bt corn was compared with a control non-Bt isoline using chickens as the experimental animal.

Aulrich et al. (1998) conducted a 5-d feeding trial in which either Bt or non-Bt corn of an isoline (Cesar) was fed to laying hens. There were six hens per treatment and corn supplied 50% of the diet. Nutrient compositions of the corn and diets, including protein, fat, Lys, Met, Cys, calcium, phosphorus, magnesium, and fatty acids ($C_{16:0}$, $C_{18:0}$, $C_{18:1}$, $C_{18:2}$, $C_{18:3}$), were substantially equivalent for the Bt and non-Bt corns and diets. Digestibilities of OM and protein and metabolizable energy content of the corns and diets were not different (Table 1). Therefore, BW of the hens did not change.

German scientists (Halle et al., 1998) also conducted a 35-d feeding trial in which either Bt or non-Bt corn of an isoline (Cesar) was fed to broilers. There were 12 male chicks per treatment, and 50% of the diet was corn. There were no significant differences between treatments for BW of the chicks at the beginning or end of the trial (Table 2). Feed intake, feed conversion, and protein digestibility also were not significantly different between treatments.

Non-Bt and Bt corns also were compared at North Carolina State University in a trial with broiler chicks from 1 to 38 d of age (Brake and Vlachos, 1998). The experimental design was a 2 × 2 × 2 factorial consisting of mash versus pellets, males versus females, and non-Bt versus Bt corn. The Bt corn was from Event 176-Hybrid 5506 BTX and the isoline was G4665. There were 32 pens with 40 birds per pen. There were only minor differences in the moisture, fat, protein, fiber, ash, and amino acid contents of the non-Bt and Bt corns (Table 3). Final BW and the percentage of birds alive at the end of the trial were not significantly different for the non-Bt and Bt treatments (Table 4). Birds that were fed diets that contained Bt corn had the best feed conversion ratio, but this improvement cannot necessarily be attributed to the source of corn because there were minor differences in the nutrient content of the diets. Most carcass components were not affected by the source of corn, but the birds fed the Bt corn had a significant increase in breast skin and Pectoralis minor yields. Although the improved feed conversion and increased breast skin and Pectoralis minor yields cannot necessarily be attributed to the Bt corn per se, it does indicate that the Bt corn did not have detrimental effects on feed conversion and chick growth.

Composition and In Vitro Digestibility of Corn Silage

Corn plants were collected from nine locations in Iowa, Illinois, Indiana, South Dakota, and Wisconsin to evaluate nutritive characteristics of fresh and ensiled whole plant material from several commercially available MON 810 Bt corn hy-

Table 4. Chick growth, feed efficiency, and carcass components.[1]

Item	Corn		
	Non-Bt G4665	Bt[2] 5506BTX	SE
Final BW, kg	1.802	1.825	44
Feed/gain, g/g[3]	1.75[a]	1.72[b]	0.01
Alive, %[4]	97.8	96.1	0.8
Carcass components, % BW			
Neck	5.67	5.74	0.05
Legs	10.59	10.50	0.06
Thighs	12.26	12.52	0.10
Wings	8.24	8.19	0.04
Fat pad	1.36	1.42	0.05
Breast skin	1.89[a]	2.08[b]	0.04
Pectoralis major	13.56	13.82	0.11
Pectoralis minor	3.27[a]	3.39[b]	0.03
Ribs and back	17.0	16.7	0.24

[a,b]Significantly different ($P < 0.05$).

[1]Brake and Vlachos (1998).

[2]From Event 176.

[3]Adjusted feed/gain = feed consumed/(live BW + BW of dead birds).

[4]Percentage of birds remaining alive at the end of trial.

Table 5. Least squares means for nutrient composition and in vitro digestibility of non-Bt near-isoline (control) and Bt (MON810) corn silages harvested at 1/4 to 1/3 milk line or at early blacklayer stage of harvest.[1,2,3]

	¼ to 1/3 Milk line			Blacklayer		
Item	Non-Bt near-isoline	Bt MON810	SEM	Non-Bt near-isoline	Bt MON810	SEM
Moisture, %	64.7	64.0	2.47	59.9	59.0	3.10
CP, %	7.88	8.00	0.241	8.27	8.30	0.297
Neutral detergent insoluble protein, %	0.873	0.796	0.602	0.949	0.871	0.0779
Ash, %	4.26	4.04	0.257	4.21	3.95	0.334
ADF, %	23.7	22.7	1.69	24.1	21.7	2.19
NDF, %	37.3	36.2	1.92	37.3	35.6	2.51
Lignin, %	2.49	2.37	0.197	2.87	2.66	0.256
Cell wall digestibility, %	45.6	45.6	1.17	41.0	40.4	1.51
In vitro true digestibility, %	79.7	80.3	1.14	78.0	79.0	1.49
In vitro dry matter digestibility, %	72.6	73.6	1.41	70.5	73.6	1.83
Starch, %	33.4	34.6	2.33	34.7	36.7	3.05
Non-fiber carbohydrate, %	49.5	50.5	2.03	78.0	79.0	1.49
Oil, %	2.86	2.97	0.227	3.25	3.46	0.283
Total digestible nutrients, %	72.6	73.8	1.62	71.1	73.4	2.11
NE_L, Mcal/kg	1.674	1.700	0.385	1.619	1.667	0.0500
NE_M, Mcal/kg	1.474	1.526	0.436	1.460	1.507	0.0579
NE_G, Mcal/kg	0.890	0.938	0.392	0.879	0.914	0.0520

[1]Faust (1999).
[2]All data except for moisture are on a DM basis.
[3]Average of two or three samples from each of nine different locations in five states.

brids and their respective non-Bt near-isogenic control hybrids (Faust, 1999; Faust and Spangler, 2000). Corn plants were harvested at 1/4 and 1/3 milk lines and at the blacklayer stage of development. Whole plant material was chopped and ensiled using PVC mini silos. Nutrient composition and in vitro digestibility were determined on freshly chopped material and silage after 60 d of fermentation. When harvested at early blacklayer the fresh whole plant material from Bt hybrids had more moisture, stayed green longer, and had a lower ammonia bound N content than the non-Bt hybrids. These scientists concluded that silage made from the Bt hybrids and their non-Bt near-isogenic hybrids were similar for nutrient composition and important feeding-related characteristics (Table 5). In vitro digestibility of DM and cell walls from Bt and non-Bt corn silage harvested at 1/4 to 1/3 milk line and at early blacklayer stages of development were not significantly different. These findings suggest similar feeding values for silages made from Bt and non-Bt hybrids during all phases of typical corn silage maturity.

Lactating Dairy Cows

At Iowa State University, 12 lactating Holstein cows were used to investigate the feeding value of whole plant green chop from Bt and non-Bt corn hybrids (Faust and Miller, 1997; Faust, personal communication, 2000). Fresh, chopped, whole, green corn plants from two Bt corn hybrids (Event 176 and Bt 11) and from a control isogenic non-Bt hybrid were fed in diets of the cows for 14 d. Green chopped corn plants were fed to maximize the intake of the Bt protein because Bt protein is degraded when the corn plant is ensiled. There were no significant differences among treatments for feed intake, milk production, or fat, protein, lactose, total solids, and urea in milk (Table 6).

Table 6. Least squares means for feed intake, milk production, and milk component percentages from dairy cows fed non-Bt and Bt whole plant green chop corn.[1]

Item	Isogenic control	Bt Event 176	Bt11	SEM
Feed intake, kg as fed/d	43.4	44.8	47.0	1.0
Milk, kg/d	40.4	39.5	38.2	1.96
Fat, %	3.41	3.50	3.47	0.183
Protein, %	2.72	2.66	2.80	0.082
Lactose, %	4.77	4.78	4.88	0.067
SNF, %	8.18	8.12	8.37	0.117
Total solids, %	11.59	11.63	11.84	0.289
Milk urea N, mg/dl	16.9	17.2	19.4	1.38

[1]Faust (personal communication, 2000).

Sixteen lactating Holstein cows in a replicated 4 × 4 Latin square design with 21-d periods were used to evaluate the effects of early (N4242) and late (N7333) maturing corn with or without the Bt gene from Event Bt 11 at the University of Nebraska (Folmer et al., 2000b; T. Klopfenstein and R. Grant, personal communication, 2000). Therefore, the four treatments were non-Bt early-maturing corn, Bt early-maturing corn, non-Bt late maturing corn, and Bt late maturing corn. The diets

Table 7. Effect of Bt gene in early or late maturing corn silages on feed intake and production of milk and milk components by dairy cows.[1]

	Early-maturing N4242		Late-maturing N7333		
Item	Non-Bt	Bt[2]	Non-Bt	Bt[2]	SEM
DMI					
kg/d	22.4	22.8	22.7	23.2	0.1
% of BW	3.72	3.75	3.75	3.84	0.02
BW					
kg	615	619	621	615	3.0
Change/21-d period	22.7	21.4	18.0	21.1	1.9
Milk, kg/d	28.6	29.2	28.5	28.7	0.3
Fat					
%	3.82	3.80	3.73	3.70	0.06
kg/d	1.09	1.11	1.06	1.06	0.02
Protein					
%	3.55	3.54	3.52	3.51	0.02
kg/d	1.01	1.03	1.00	1.01	0.01
Lactose					
%	4.85	4.90	4.80	4.87	0.40
kg/d	1.38	1.43	1.37	1.40	0.04
4% FCM, kg/d	27.7	28.3	27.3	27.4	0.5
FCM/DMI, kg/kg	1.24	1.26	1.20	1.19	0.03

[1]Folmer et al. (2000b); Klopfenstein and Grant (personal communication, 2000).
[2]Event Bt11. The event was a single insertion of transgenic DNA into the plant genome to produce Bt corn.

Table 8. Digestibilities (%) of nutrients in Non-Bt and Bt corn silage by sheep.[1]

	Corn silages	
Digestibility	Non-Bt (Cesar)	Bt
OM	75.0	74.5
Fat	76.3	79.8
Fiber	66.7	68.1
NFE[2]	81.2	80.8

[1]Daenicke et al. (1999).
[2]NFE = Nitrogen-free extract.

Table 9. Composition of Non-Bt and Bt corn silages, feed intake, and performance of Holstein bulls fed corn silage.[1]

	Corn silages	
Item	Non-Bt (Cesar)	Bt
Silage composition		
DM, %	33.7	32.1
OM, %	95.5	95.8
CP, %	8.4	8.7
Crude fat, %	2.9	2.8
Crude fiber, %	18.6	19.1
Metabolizable energy, MJ/kg	10.95	10.91
Feed intake		
Concentrate, kg/d	1.78	1.80
Corn silage, kg/d	18.8	18.7
DMI, kg/d	8.00[a]	7.78[b]
Protein intake, g/d	1102	1110
Metabolizable energy intake, MJ/d	91.2[a]	88.6[b]
Steer performance		
Final BW, kg	537.0	534.5
ADG, g/d	1487	1482
Metabolizable energy/BW gain, MJ/kg	61.5	60.1
Hot carcass weight, kg	281.3	282.0
Dressing, %	52.4	52.8
Abdominal fat, kg	49.6	48.7

[a,b]Means with different superscripts are different ($P < 0.05$).
[1]Daenicke et al. (1999).

contained 40% corn silage, 28% corn grain from the same corn as the silage to maximize the hybrid effect, 10% alfalfa silage, and 22% of a protein, mineral, and vitamin mixture. There was no effect of the Bt trait in either the early or late maturing corn on DMI, milk production, milk composition, milk component yields, 4% FCM production, efficiency of FCM production (Table 7), ruminal pH, concentration of VFA in rumen fluid, or in situ NDF digestion kinetics.

Bt (Event 176) and non-Bt (isogenic Rh208) corn was grown in two locations in France (Y, Barriere, P. Brunschwig, F. Surault, and J.C. Emile, personal communication, 2000) and harvested as silage. Twenty-four dairy cows were fed either the Bt or non-Bt corn silage in diets that contained 73% corn silage and 27% concentrate for 13 wk. Dry matter intake was 1 kg/cow per day greater for cows fed the Bt silage. Milk production (33 kg/d per cow) and the CP, fat, and fatty acid composition of milk were not affected by the source of corn silage. The authors concluded that the feeding value for the Bt and non-Bt corn silages were equal.

Sheep

French scientists (Barriere, Brunschwig, Surault, and Emile, personal communication, 2000) compared Bt (Event 176) and non-Bt (isogenic Rh208) corn silages in a 15-d digestibility trial with wethers. Twenty-four wethers were fed Bt corn silage and 12 wethers were fed non-Bt corn silage. Net energy values for the corn silages fed at maintenance to the wethers and digestibilities of OM, crude fiber, and NDF were not different for Bt and non-Bt corn silages.

German scientists (Daenicke et al., 1999) also determined digestibility of Bt and non-Bt isogenic (Cesar) corn silage supplemented with protein using sheep. Four wethers were fed either Bt or non-Bt corn silage. Digestibilities of both silages were high, and there were no significant differences between the silages for digestibility of OM, fat, fiber, or nitrogen-free-extract (Table 8).

Feedlot Cattle Fed Corn Silage

Daenicke et al. (1999) compared Bt and non-Bt isogenic (Cesar) corn silages as feeds for German Holstein bulls. Twenty bulls per treatment were assigned to a diet of either Bt or non-Bt corn silage plus a constant intake of concentrate. Bulls were about 165 d of age, initially weighed about 188 kg, and were fed corn silage until they weighed about 550 kg. There was no difference in the nutrient composition of the corn silages (Table 9). Bulls fed Bt and non-Bt corn silages consumed the same amount of concentrate and similar amounts of as fed corn silage. Because the Bt silage was slightly lower in DM, bulls fed this silage consumed less DM and energy than bulls fed non-Bt silage. However, average daily gain (**ADG**), hot carcass weight, dressing percentage, and abdominal fat were not different for bulls fed the Bt and non-Bt corn silage.

To compare Bt (Event Bt 11) and non-Bt isogenic corn silages and early (N4242) and late (N7333) maturing corn silages, nutritionists at the University of Nebraska (Folmer et al., 2000a; Klopfenstein, personal communication, 2000) assigned 128 steers that weighed 282 kg to a 2 × 2 factorial arrangement of treatments. Diets on a DM basis were 90% corn silage and 10% protein supplement (75% soybean meal and 25% urea on a N basis). The trial was 101 d in length. Dry matter intake was greater for steers fed Bt than non-Bt corn silage (Table 10). There was a significant interaction between the Bt trait and the hybrid genotype for ADG and efficiency of feed utilization by steers. Average daily gain was greater for steers fed the Bt early-maturing corn silage compared with the non-Bt early-maturing corn silage but was similar for steers

Table 10. Performance of growing steers fed non-Bt and Bt corn silages that mature early and late.[1]

	Early-maturing N4242		Late-maturing N7333			*P*-Values		
Item	Non-Bt	Bt[2]	Non-Bt	Bt[2]	SEM	Gene[3]	Hybrid	Interaction
DMI, kg/d	8.42	8.71	8.22	8.51	0.11	0.02	0.09	0.96
Initial wt, kg	282	281	282	281	0.45	0.08	0.88	0.93
Final wt, kg	419[bc]	428[c]	413[bd]	407[d]	3.3	0.56	0.002	0.04
ADG, kg/d	1.36[b]	1.46[c]	1.30[b,d]	1.25[d]	0.03	0.39	<0.001	0.03
Feed/gain, kg/kg	6.22[bc]	5.98[b]	6.33[c]	6.81[d]	0.11	0.32	<0.001	<0.01

[b,c,d] Means in the same row not bearing a common superscript differ ($P < 0.05$).
[1]Folmer et al. (2000a) and Klopfenstein (personal communication, 2000).
[2]Event Bt11.
[3]Gene = Bt versus non-Bt.

fed Bt and non-Bt late maturing corn silage. Efficiency of feed utilization was better for steers fed non-Bt than Bt late maturing corn silage but was similar for Bt and non-Bt early-maturing corn silage. Incorporation of the Bt gene into the two different corn hybrids appeared to have different effects on performance of the steers. This effect was suggested to be related to the nutrient composition of the two corn hybrids from which the Bt corn was developed. Steers fed the early-maturing corn silage gained 11% faster ($P < 0.01$) and were 7% more efficient in feed utilization ($P < 0.01$) than steers fed late maturing silage; however, the presence of the Bt gene in the corn hybrids did not consistently affect performance of the steers. Therefore, the genetics of the parent corn hybrid appeared to have a greater effect on animal performance than did the incorporation of the Bt gene into the corn.

For 2 yr, scientists (Hendrix et al., 2000) at Purdue University grew Bt and non-Bt corn silage to feed to steers. Each year, 56 steers were fed either Bt or non-Bt whole plant corn silage for about 87 d to determine animal performance. Dry matter intake (8.88 vs. 8.67 kg/d) and ADG (1.30 vs. 1.34 kg/d) were not different for steers fed Bt or non-Bt corn silage; however, efficiency of feed utilization (6.86 vs. 6.48 kg DM/kg gain) was better for steers fed non-Bt corn silage. These scientists concluded there were no major differences in feeding value of these corn silages.

Grazing Beef Cattle

Three experiments have been conducted to investigate the effects on beef cattle of grazing corn residue that contained the Bt trait. Russell et al. (2000a, 2000b) planted one non-Bt corn hybrid (Pioneer 3489) and three Bt-corn hybrids (Pioneer 34R07, YieldGard event; Novartis NX6236, YieldGard event; and Novartis N64-Z4, Knockout event) in duplicate 2.9 ha fields. After the harvest of grain, three mature cows in mid-gestation were assigned to duplicate fields for each treatment (six cows/treatment) to strip-graze for 126 d. Six cows also were assigned to duplicate drylots. All cows were fed alfalfa-grass hay to maintain a BCS of five on a nine-point scale. There were no differences in yields of grain or dropped grain. Dry matter and OM contents and yields of in vitro digestible DM were not different for these sources of corn residue. Source of corn residue did not affect the mean rates of change in composition of corn residue during the 126 d of grazing. There were no significant differences in BW or BCS of cows among treatments (Table 11). To maintain similar BCS, cows grazing corn residues required a smaller quantity of hay than did cows maintained in drylot. The amount of hay required to maintain body condition of the cows was not different for cows fed the non-Bt and the Bt corn residues.

Sixty-seven steers that weighed on average 284 kg were used in a two-part, 70-d trial to evaluate their performance when fields of Bt N7333 and isogenic non-Bt N7333 corn residues were grazed (Folmer et al., 2000a; Klopfenstein, personal communication, 2000). Fifty-one steers were assigned to the fields to achieve equal stocking rate per hectare for the Bt (27 steers) and non-Bt (24 steers) fields. Sixteen additional steers were used to evaluate grazing preference for the Bt and non-Bt corn residue. Steers were fed 0.45 kg of protein supplement/head per day to ensure that protein did not limit animal performance. Average daily gain and grazing preference were not different for steers grazing Bt and non-Bt corn residues (Table 12).

Table 11. Changes in BW and condition score of cows grazing corn residue and fed hay.[1]

Item	Corn residue and hay[2]				
	Pioneer3489 Non-Bt	Pioneer 34R07 Bt[3]	Novartis NX6236 Bt[3]	Novartis N64-24 Bt[4]	Drylot fed hay
Initial					
BW, kg	637	619	639	624	633
Condition score	5.0	5.0	5.0	5.1	5.0
Change					
BW, kg	31	43	32	37	31
Condition score	0.1	–0.2	–0.3	0	–0.1
Hay fed kg DM/cow	650[a]	628[a]	625[a]	541[a]	1447[b]

[a,b]Differences between treatment means with different superscripts are significant ($P < 0.05$).
[1]Russell et al. (2000a, 2000b).
[2]Hay fed to maintain BCS of five on nine-point scale.
[3]YieldGard event. The event was a single insertion of transgenic DNA into the plant genome to produce Bt corn.
[4]Knockout event. The event was a single insertion of transgenic DNA into the plant genome to produce Bt corn.

Table 12. Performance and grazing preference of growing steers grazing Non-Bt and Bt corn residue.[1]

Item	Corn residue N7333 Non-Bt	Corn residue N7333 Bt[2]	SEM
Initial wt, kg	284	284	0.35
Final wt, kg	306	301	2.0
ADG, kg/d	0.32	0.24	0.03
Grazing preference,[3] %	52.5	47.5	5.2

[1]Folmer et al. (2000a) and Klopfenstein (personal communication, 2000).
[2]Event Bt11. The event was a single insertion of transgenic DNA into the plant genome to produce Bt corn.
[3]Percentage of steers observed grazing Non-Bt and Bt corn residue.

Hendrix et al. (2000) used 78 nonlactating pregnant beef cows during 2 yr for an average of 38 d per year to determine performance of cows grazing Bt or isogenic non-Bt corn residues. Twenty additional cows were given access to both Bt and isogenic non-Bt corn residues in yr 1 to determine grazing preference. There were no differences in average BW change or choice of grazing preference by cows grazing Bt or non-Bt corn residue. There were no major differences in feeding value of these corn residues.

HERBICIDE-TOLERANT CORN

Glyphosate-tolerant crop varieties have been developed and commercialized for corn, soybeans, canola, and cotton (Sidhu et al., 2000). Research trials have been conducted to investigate the nutrient composition and the feeding value of glyphosate-tolerant corn for food producing animals. Two feeding trials have been conducted, one with growing broiler chickens and one with lactating dairy cows to evaluate this genetically enhanced corn. |

Table 13. Nutrient composition of whole plant green chop from a control parental line (DK580), a glyphosate-tolerant line (GA21/DK580), and five commercial lines of corn generated from multiple field sites over a period of 2 yr (1996 to 1997).[1]

	1996		1997			
Item	Control	GA21/DK580	Control	GA21/DK580	Commercial lines	Historical range[2]
Moisture, %	65.52	72.30	68.73	68.83	68.31	68.7–73.5
Protein, % DM	7.58	7.91	7.45	7.49	7.20	4.8–8.4
Fat, %DM	1.50	1.73	2.21	1.88	2.04	1.4–2.1
Ash, % DM	3.85	4.22	4.26	4.29	4.19	2.9–5.1
ADF, % DM	25.89	25.04	25.55	23.85	25.56	21.4–29.2
NDF, % DM	40.85	39.47	38.92	37.91	39.54	39.9–46.6
Carbohydrates, % DM	87.04	86.14	86.06	86.35	86.62	84.6–89.1
Calcium, % DM	0.1766	0.1934	0.2177	0.2304	0.1948	NA
Phosphorus, % DM	0.2124	0.2288	0.2179	0.2178	0.1992	NA

[1]Sidhu et al. (2000).
[2]Denotes the lowest and highest individual values across sites from conventional control values determined from previous studies.
NA = Not available.

Table 14. Nutrient composition of grain from a control parental line (DK580), a glyphosate-tolerant line (GA21/DK580), and five commercial lines of corn generated from multiple field sites over a period of two years (1996-1997).[1]

	1996		1997				
Item	Control	GA21/DK580	Control	GA21/DK580	Commercial lines	Literature range	Historical range[2]
Moisture, %	14.40	14.15	16.21	16.86	16.30	7–23	9.4–15.8
Protein, % DM	10.05	10.05	10.54	11.05	10.87	6.0–12.0	9.0–13.6
Fat, %DM	3.55	3.51	3.98	3.90	3.69	2.9–6.1	2.4–4.2
Ash, % DM	1.27	1.27	1.56	1.38	1.79	1.1–3.9	1.2–1.8
ADF, % DM	3.72	3.73	6.35	6.35	6.06	3.3–4.3	9.6–15.3
NDF, % DM	11.70	10.82	9.80	9.33	10.12	8.3–11.9	3.1–5.3
Carbohydrates, % DM	85.15	85.15	83.79	83.66	83.68	NA	81.7–86.3
Calcium, % DM	0.0027	0.0026	0.0043	0.0039[a]	0.0040	0.01–0.1	0.0029–0.006
Phosphorus, % DM	0.299	0.299	0.326	0.326	0.330	0.26–0.75	0.288–0.363

[a]Different from control ($P < 0.05$).
[1]Sidhu et al. (2000)
[2]Denotes the lowest and highest individual values across sites from conventional control values determined from previous studies.
NA = Not available.

Table 15. Amino acid composition of grain from a control parental line (DK580), a glyphosate-tolerant line (GA21/DK580), and five commercial lines of corn generated from multiple field sites over a period of two years (1996-1997).[1]

	1996		1997				
Amino acid	Control	GA21/DK580	Control	GA21/DK580	Commercial lines	Literature range	Historical range[2]
	% of total amino acids						
Ala	7.64	7.62	7.62	7.64	7.78	6.4–9.9	7.2–8.8
Arg	4.30	4.13	4.51	4.48	4.36	2.9–5.9	3.5–5.0
Asp	6.78	6.71	6.65	6.63	6.57	5.8–7.2	6.3–7.5
Cys	2.11	2.10	2.28	2.22	2.19	1.2–1.6	1.8–2.7
Glu	19.06	19.27	18.70	18.78	19.17	12.4–19.6	18.6–22.8
Gly	3.78	3.72	3.89	3.83	3.71	2.6–4.7	3.2–4.2
His	2.84	2.81	2.74	2.67	2.80	2.0–2.8	2.8–3.4
Ile	3.58	3.60	3.57	3.53	3.75	2.6–4.0	3.2–4.3
Leu	12.90	13.11	12.87	12.98	13.32	7.8–15.2	12.0–15.8
Lys	3.09	3.02	3.02	3.11	2.96	2.0–3.8	2.6–3.5
Met	2.03	1.98	2.17	2.16	2.02	1.0–2.1	1.3–2.6
Phe	5.17	5.15	5.33	5.31	5.36	2.9–5.7	4.9–6.1
Pro	8.69	8.69	9.00	8.98	9.16	6.6–10.3	8.7–10.1
Ser	5.27	5.33[a]	5.03	5.17	4.64	4.2–5.5	4.9–6.0
Thr	3.73	3.77	3.54	3.59	3.43	2.9–3.9	3.3–4.2
Trp	0.57	0.62	0.61	0.61	0.59	0.5–1.2	0.4–1.0
Tyr	3.95	3.81[a]	3.77	3.73	3.48	2.9–4.7	3.7–4.3
Val	4.64	4.58	4.62	4.57	4.79	2.1–5.2	4.2–5.3

[a]Different from control ($P < 0.05$).
[1]Sidhu et al. (2000).
[2]Denotes the lowest and highest individual values across sites from conventional control values determined from previous studies.

Table 16. Fatty acid composition of grain from a control parental line (DK580), a glyphosate-tolerant line (GA21/DK580), and five commercial lines of corn generated from multiple field sites over a period of 2 yr (1996 to 1997).[1]

Fatty acid	1996 Control	1996 GA21/ DK580	1997 Control	1997 GA21/ DK580	1997 Commercial lines	Literature range	Historical range[2]
	% of total fatty acids						
Arachidic (20:0)	0.41	0.40	0.36	0.37	0.40	0.1–2	0.3–0.5
Behenic (22:0)	0.17	0.16	0.15	0.16	0.18	NA	0.1–0.3
Eicosenoic (20:1)	0.29	0.28	0.30	0.30	0.30	NA	0.2–0.3
Linoleic (18:2)	58.72	58.56	61.51	61.40	59.18	35–70	55.9–66.1
Linolenic (18:3)	1.08	1.10	1.14	1.14	1.11	0.8–2	0.8–1.1
Oleic (18:1)	27.40	27.50	24.10	24.20	26.20	20–46	20.6–27.5
Palmitic (16:0)	9.92	9.94	10.72	10.70	10.58	7–19	9.9–12.0
Stearic (18:0)	1.86	1.87	1.67	1.68	1.88	1–3	1.4–2.2

[1]Sidhu et al. (2000).
[2]Denotes the lowest and highest individual values across sites from conventional control values determined from previous studies.

Composition

Grain and whole plant green chop from glyphosate-tolerant corn (GA21), a control parental line (DK626), and five commercial hybrids were analyzed for nutrient composition (Sidhu et al., 2000). Results of these analyses indicated that, except for a few small differences that probably are not biologically significant, moisture, protein, fat, ash, carbohydrate, ADF, NDF, amino acid, fatty acid, calcium, and phosphorus contents of the corn grain and whole plant green chop were not significantly different (Tables 13, 14, 15, and 16). Therefore, the glyphosate-tolerant corn grain and green chop were substantially equivalent in composition to the control and commercial corn varieties.

Chickens

A control parental line (DK580), a glyphosate-tolerant line (GA21/DK580) and five commercial varieties of corn were evaluated with 560 growing broiler chickens (80/treatment) in a 39-d growth trial (Sidhu et al., 2000). Growth, feed efficiency, feed efficiency adjusted for feed consumption of dead chickens, and fat pad weights were not different for chickens fed the control or glyphosate-tolerant corn (Table 17). Likewise, these same measurements were not different for chickens fed the glyphosate-tolerant corn and the population mean for chickens fed the five commercial corn varieties.

Table 17. Performance of chickens fed a control parental line (DK580), a glypohosate-tolerant line (GA21/DK580), and five commercial lines of corn.[1]

Item	Mean final BW (kg)	Feed efficiency[2]	Feed efficiency (Adj)[3]	Fat pad wt[4]
Males				
Control	1.945	1.662	1.629	1.638
GA21/DK580	2.013	1.750	1.646	1.775
Commercial lines[5]	1.947	1.699	1.650	1.625
Females				
Control	1.859	1.779	1.721	2.114
GA21/DK580	1.885	1.781	1.749	2.085
Commercial lines[5]	1.874	1.789	1.744	2.119

[1]Sidhu et al. (2000).
[2]Total feed consumption per pen divided by total BW of surviving chickens.
[3]Total feed consumption per pen divided by total BW of surviving chickens and the weight of chickens that died or were removed from pens.
[4]Fat pad wt as percentage of BW.
[5]Mean of five commercial lines of corn tested separately.

Dairy Cows

Sixteen multiparous Holstein cows from 71 to 107 d in milk were assigned to two groups and used in a switchback design with three periods of 28 d each to evaluate the feeding value of glyphosate-tolerant corn or a control isogenic line (DK626) of corn (Donkin, personal communication, 2000). Cows were fed for ad libitum intake diets that contained 62% corn silage, 17% corn grain, and 21% protein, mineral, and vitamin supplement. There were no differences in DMI, milk production, 4% FCM production, SCC, milk urea N, or percentages and yields of protein, fat, lactose, and SNF in milk when cows were fed glyphosate-tolerant corn or the isogenic line of corn (Table 18).

GLYPHOSATE-TOLERANT SOYBEANS

Soybeans have been genetically enhanced and commercialized by introducing a single gene that makes the soybean plant tolerant to the herbicide glyphosate. This modification allows farmers to spray fields of soybeans with this herbicide to kill weeds without killing the soybeans. Composition of the glyphosate-tolerant soybeans and products from their processing as well as their feeding value for chickens and dairy cattle

Table 18. Effects of feeding glyphosate-tolerant (DK626RR) or an isogenic parent line (DK626) of corn silage and corn grain to dairy cows on feed intake, milk production, and milk components.[1]

Item	Control DK626	Glyphosate-tolerant DK626RR	SE
DMI, kg/d	21.5	21.8	0.4
Milk, kg/d	29.4	29.5	0.4
4% FCM, kg/d	27.5	27.8	0.4
SCC, x 1000	101	99	10
MUN,[2] mg/dl	10.8	10.9	0.8
Milk protein			
%	3.25	3.24	0.01
kg/d	0.96	0.96	0.01
Milk fat			
%	3.55	3.61	0.04
kg/d	1.04	1.06	0.02
Milk lactose			
%	4.70	4.72	0.01
kg/d	1.40	1.40	0.02
Milk SNF			
%	8.74	8.75	0.02
kg/d	2.58	2.59	0.04

[1]Donkin (personal communication, 2000).
[2]MUN = Milk urea nitrogen.

Table 19. Composition of a control parental line and genetically enhanced glyphosate-tolerant soybeans (GTS) from 1992 and 1993 US field trial.[1]

Item	Control A5403	Genetically enhanced GTS 40-3-2	GTS 61-67-1	Literature range
1992 (9 sites)				
Moisture, %	8.12	8.12	8.20	7–11
Protein, % DM	41.6	41.4	41.3	36.9–46.4
Ash, % DM	5.04	5.24*	5.17*	4.61–5.37
Fat, % DM	15.52	16.28*	16.09	13.2–22.5
Fiber, %DM	7.13	6.87	7.08	4.7–6.48
Carbohydrates, % DM	38.1	37.1*	37.5	30.9–34.0
1993 (4 sites)				
Moisture, %	6.12	6.34	NT	
Protein, % DM	41.5	41.4	NT	
Ash, % DM	5.36	5.43	NT	
Fat, % DM	20.11	20.42	NT	
Fiber, %DM	6.71	6.63	NT	
Carbohydrates, % DM	33.0	32.7	NT	

[1]Padgette et al. (1996).
*Significantly different from the control line ($P < 0.05$).
NT = Not tested.

Table 20. Amino acid composition of a control parental line and genetically enhanced glyphosate-tolerant soybeans (GTS) from a nine-site 1992 US field trials.[1]

Amino acid	Control A5403	Genetically enhanced GTS 40-3-2	GTS 61-67-1	Literature range
	g/100 g DM			
Asp	4.53	4.42	4.48	3.87–4.98
Thr	1.60	1.56	1.58	1.33–1.79
Ser	2.10	2.04	2.07	1.81–2.32
Glu	7.34	7.10	7.26	6.10–8.72
Pro	2.03	1.98	2.02	1.88–2.61
Gly	1.72	1.67	1.69	1.88–2.02
Ala	1.71	1.67	1.69	1.49–1.87
Val	1.85	1.80	1.83	1.52–2.24
Ile	1.78	1.73	1.76	1.46–2.12
Leu	3.05	2.97	3.03	2.71–3.20
Tyr	1.45	1.40	1.43	1.12–1.62
Phe	1.97	1.90	1.95	1.70–2.08
His	1.06	1.03	1.04	0.89–1.08
Lys	2.61	2.56	2.58	2.35–2.86
Arg	2.94	2.85	2.90	2.45–3.49
Cys	0.60	0.62	0.60	0.56–0.66
Met	0.55	0.55	0.54	0.49–0.66
Trp	0.59	0.59	0.58	0.53–0.54

[1]Padgette et al. (1996).

have been investigated in research trials.

Composition

Padgette et al. (1996) extensively investigated the composition of two glyphosate-tolerant soybeans (40-3-2 and 61-67-1) and a control parental soybean variety (A5403) from 13 fields during 2 yr. Nutrients measured in the soybean seeds included nutrients by proximate analyses (protein, fat, fiber, ash, carbohydrates), amino acids, and fatty acids. Antinutrients measured in the soybean seed or toasted meal were trypsin-inhibitor, lectins, isoflavones, stachyose, raffinose, and phytate. Nutrients by proximate analyses were determined for defatted toasted meal, defatted nontoasted meal, protein isolate, and protein concentrate prepared from the three soybean varieties. Fatty acid composition of soybean oil from the three varieties also was measured. Statistically significant differences were detected between the control and glyphosate-tolerant soybean seeds for some of the nutrients determined by proximate analyses (Table 19). However, these differences were small and were considered biologically unimportant. There were no significant differences in anti-nutrient, amino acid (Table 20), or fatty acid (Table 21) content. These data indicated that the composition of control and glyphosate-tolerant soybeans were substantially equivalent.

Table 21. Fatty acid composition of a control parental line and genetically enhanced glyphosate-tolerant soybeans (GTS) from a nine-site 1992 US field trial.[1]

Fatty acid	Control A5403	Genetically enhanced GTS 40-3-2	GTS 61-67-1	Literature range
	g/100 g			
6:0	0.11	0.11	0.11	
16:0	11.19	11.21	11.14	7–12
17:0	0.13	0.13	0.13	
18:0	4.09	4.14	4.05	2–5.5
18:1*cis*	19.72	19.74	19.81	20–50
18:2	52.52	52.31	52.48	35–60
18:3	8.02	8.23	8.12	2–13
20:0	0.36	0.37	0.35	
20:1	0.17	0.17	0.17	
22:0	0.50	0.53*	0.49	
24:0	0.18	0.19	0.18	
Unknowns	2.63	2.48	2.59	

[1]Padgette et al. (1996).
*Significantly different from the control line ($P < 0.05$).

Table 22. Body weight gain, feed intake, gain:feed ratio, survival, and breast and fat pad weights of chickens fed soybean meal processed from glyphosate-tolerant (GTS) varieties or a control parental line of soybeans during a 42-d study.[1,2]

Item	Control A5403	Genetically enhanced GTS 61-67-1	GTS 40-3-2
BW, g	2192	2188	2144
Wt gain, g/d	51	51	50
Feed intake, g/d	93	93	92
Gain:feed, g/g	0.551	0.548	0.546
Survival, %	90.8	89.2	91.7
Breast wt, g	302	296	294
Fat pad wt, g	81	82	77

[1]Hammond et al. (1996).
[2]120 chicks (1/2 male and 1/2 female) were used in the trial from hatching to 42 d posthatching.

Chickens

Three hundred and sixty broiler chickens were used from birth to 42 d of age to evaluate the feeding value of soybean meal produced from two glyphosate-tolerant soybeans (40-3-2 and 61-67-1) and a control parental variety (A5403) (Hammond et al., 1996). The experimental design was a 3 × 2 factorial arrangement with three soybean varieties and two sexes of chickens (equal numbers). At the end of the 42-d experiment there were no significant differences among sources of soybean meal for BW, live weight gain, feed intake, gain:feed ratio, survival, breast muscle, or fat pad weight of chickens (Table 22).

Lactating Dairy Cows

To further evaluate these glyphosate-tolerant soybeans, 36 multiparous Holstein cows ranging from 93 to 196 DIM at the start of the experiment were fed TMR that contained 10.2% of one of three whole raw soybeans on a DM basis (Hammond et al., 1996). The soybeans were two lines of glyphosate-tolerant (40-3-2 and 61-67-1) and a control parental variety (A5403). The trial was 29 d long, with digestibility and N balance determined from d 21 to 28, and ammonia and VFA concentrations in rumen fluid determined on d 29. Differences among

Table 23. Dry matter and net energy intakes and production and composition of milk from cows fed a control parental line or genetically enhanced glyphosate-tolerant soybeans (GTS) during a 29-d trial.[1]

Item	ControlA5403	Genetically enhanced GTS61-67-1	Genetically enhanced GTS40-3-2
Number of cows	11	12	12
DMI, kg/d	24.4	25.4	24.7
NE_L intake, MJ/d	167.8	180.4	179.6
Milk, kg/d	34.9	36.2	36.2
3.5% FCM, kg/d	34.1[a]	36.6[b]	36.8[b]
Fat, %	3.37	3.62	3.59
Protein, %	3.28	3.29	3.23
Lactose, %	4.72	4.75	4.72
SCC × 10^3	110	59	93
FCM/NE_L intake, kg/MJ	0.19	0.21	0.21

[a,b]Means in the same row not bearing a common superscript differ ($P < 0.05$).
[1]Hammond et al. (1996).

Table 24. Milk production, feed intake, DM digestibility, and nitrogen balance of cows fed a control parental line or genetically enhanced glyphosate-tolerant soybeans (GTS) during a 7-d total collection trial.[1]

Item	Control A5403	Genetically enhanced GTS 61-67-1	Genetically enhanced GTS 40-3-2
Number of cows	10	12	11
Milk, kg/d	33.6	35.5	34.4
DMI, kg/d	23.8	25.7	23.8
DM digestibility, %	69.0	69.4	68.6
Nitrogen intake, g/d	840	874	851
Milk nitrogen, g/d	214	230	214
Urine nitrogen, g/d	446	466	467
Fecal nitrogen, g/d	236	248	240
Absorbed nitrogen, g/d	597	641	601
Retained nitrogen, g/d	-68	-55	-76
Productive nitrogen,[2] g/d	147	175	138

[1]Hammond et al. (1996).
[2]Productive nitrogen is milk nitrogen plus retained nitrogen.

treatments were not significant for DM, NE_L, or N intakes; milk production; 3.5% FCM/NE_L; percentages of protein, fat, or lactose in milk; somatic cell count (Table 23); DM digestibility; N absorbed or retained; N excreted in feces and urine (Table 24); and concentration of ammonia N or molar percentages of VFA in ruminal fluid. Production of 3.5% FCM was greater for cows fed glyphosate-tolerant soybeans because both milk production and milk fat percentage were slightly but not significantly greater than for cows fed the control parental variety. These data indicate that the feeding value of these sources of soybeans are substantially equivalent.

Commercial Utilization of Genetically Enhanced Crops

Modern methods of biotechnology are being accepted and used by farmers who planted about 40 million ha of genetically enhanced crops globally in 1999 (James, 1999). From 1998 to 1999 the global hectares of genetically enhanced crops increased from 27.8 million hectares to 39.9 million hectares or about 44% (James, 1999). Herbicide-tolerant soybeans grown in the United States increased from 10.2 million ha in 1998 to 15.0 million ha in 1999, equivalent to 50% of the 30.0 million ha of soybeans grown in the United States during 1999 (James, 1999). Also, genetically enhanced corn that was insect-resistant, Bt- and herbicide-tolerant, and herbicide-tolerant increased from 8.1 million ha in 1998 to 10.3 million ha in 1999, equivalent to 33% of the 31.4 million ha of corn grown in the United States in 1999 (James, 1999). Approximately 70% of the soybeans produced in the world (Clark and Bateman, 1999) and 80% of the corn produced in the United States (National Corn Group Association, 2000) are consumed by animals. Because these genetically enhanced crops were grown beginning in 1996, they have been fed to livestock. No detrimental effects have been reported when these feeds were fed to livestock, which supports findings in the research trials summarized above. This indicates that the genetically enhanced corn and soybeans that are currently available in the marketplace are substantially equivalent in composition, similar in digestibility, and have a similar feeding value for livestock.

Human Food Supply and Safety Issues Associated with Genetically Enhanced Crops

It has been estimated that the world's population will increase from the current six billion people to about 10 billion people by the year 2040. It also has been estimated that the supply of food required to adequately meet human nutritional needs over the next 40 yr is quantitatively equal to the amount of food previously produced throughout the entire history of humankind (Bauman, 1992; NRC, 1994). If we are to adequately feed this growing population, modern methods of biotechnology must be used to produce crops that supply feed for livestock and food for humans. We must be sure that these and future products produced using modern techniques of biotechnology are safe for both livestock and humans if they are to be eaten now and in the future. In this regard, Beever and Kemp (2000) in an excellent review concluded "Additionally there is a growing body of scientifically valid information available that indicates no significant risk associated with the consumption of DNA or the resulting proteins from GM crops that are registered in any of these countries. Based on the safety analyses required for each crop, consumption of milk, meat and eggs produced from animals fed GM crops should be considered to be as safe as traditional practices."

REFERENCES

Aulrich, K., I. Halle, and G. Flachowsky. 1998. Inhaltsstoffe und verdaulichkeit von maiskorern der sorte cesar und der gentechnisch veranderten Bt-hybride bei legehennen. Pages 465-468 *in* Verband Deutscher Landwirtschaftlicher Unterschungs-und Forschungsanstalten Reiche Kongreß berichte. Giessen, Germany.

Bauman, D. E. 1992. Bovine somatotropin: Review of an emerging animal technology. J. Dairy Sci. 75:3432-3451.

Beever, D. E., and C. F. Kemp. 2000. Safety issues associated with the DNA in animal feed derived from genetically modified crops. A review of scientific and regulatory procedures. Nutrition Abstracts and Reviews. Series B: Livest. Feeds Feeding 70:175-182.

Brake, J., and D. Vlachos. 1998. Evaluation of transgenic event 176 "Bt" corn in broiler chickens. Poultry Sci. 77:648-653.

Clark, J. H., and H. G. Bateman, II. 1999. Use and future prospects for use of soy products in dairy cattle diets. Pages 87-105 *in* Opportunities for Soy Products in Animal Nutrition. J. K. Drackley, ed. Federation of Animal Science Societies, Savoy, IL.

Daenicke, R., D. Gädeken, and K. Aulrich. 1999. Einsatz von silomais herkömmlicher sorten und der gentechnisch veränderten Bt-hybriden in der rinderfütterung-Mastrinder. Pages 40-42 *in* Maiskolloquium. Wittenberg, Germany.

Faust, M. A. 1999. Research update on Bt corn silage. Pages 157-164 *in* Four-State Applied Nutrition and Management Conference. Midwest Plan Service, Ames, IA.

Faust, M., and L. Miller. 1997. Study finds no Bt in milk. Iowa State University Integrated Crop Management Newsletter IC-478, Special Livestock Edition, Ames.

Faust, M. A., and S. M. Spangler. 2000. Nutritive value of silages from MON810 Bt and non-Bt near-isogenic corn hybrids. J. Dairy Sci. 83:1184 (Abstr.).

Folmer, J. D., C. E. Erickson, C. T. Milton, T. J. Klopfenstein, and J. F. Beck.

2000a. Utilization of Bt corn residue and corn silage for growing beef steers. J. Anim. Sci. 78(Suppl. 2):85 (Abstr.).

Folmer, J. D., R. J. Grant, C. T. Milton, and J. F. Beck. 2000b. Effect of Bt corn silage on short-term lactational performance and ruminal fermentation in dairy cows. J. Dairy Sci. 83:1182. (Abstr.)

Halle, I., K. Aulrich, and G. Flachowsky. 1998. Einstaz von maiskornern der sorte cesar und des gentechnisch veranderten Bt-hybriden in der broilermast. Pages 265-267 *in* Proc. 5 Tagung, Schweine-und Geflügelernährung. Wittenberg, Germany.

Hammond, B. G., J. L. Vicini, G. F. Hartnell, M. W. Naylor, C. D. Knight, E. H. Robinson, R. L. Fuchs, and S. R. Padgette. 1996. The feeding value of soybeans fed to rats, chickens, catfish and dairy cattle is not altered by genetic incorporation of glyphosate tolerance. J. Nutr. 126:717-727.

Hartnell, G. F., and F. L. Fuchs. 1999. Current and future value of innovative technology in genetically modified grains and oilseeds. Pages 69-85 *in* Fifteenth Annual Carolina Swine Nutrition Conference, Raleigh, NC.

Hendrix, K. S., A. T. Petty, and D. L. Lofgren. 2000. Feeding value of whole plant silage and crop residues from Bt or normal corns. J. Dairy Sci. 83(Suppl. 1):273 (Abstr.).

James, C. 1999. Global review of commercialized transgenic crops: 1999. No. 12: Preview. International Service for the Acquisition of Agri-Biotech Applications Briefs, Ithaca, NY.

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.

Munkvold, G. P., R. L. Hellmich, and L. G. Rice. 1999. Comparison of fumonisin concentrations in kernels of transgenic Bt maize hybrids and nontransgenic hybrids. Plant Dis. 83:130-138.

Munkvold, G. P., R. L. Hellmich, and W. B. Showers. 1997. Reduced *Fusarium* ear rot and symptomless infection in kernels of maize genetically engineered for European corn borer resistance. Phytopathology 87:1071-1077.

National Corn Growers Association. 2000. The World of Corn. U.S. Corn Consumption Livestock. Available at http://www.ncga.com/03world/main/corn_consumption_livestock.html. Accessed on 6/21/2000.

NRC. 1994. Page 3 *in* Metabolic Modifiers: Effects on the Nutrient Requirements of Food-Producing Animals. T.D. Etherton, ed. National Research Council, National Academy Press, Washington, D.C.

Ostlie, K. R., W. D. Hutchinson, and R. L. Hellmich. 1997. Bt Corn and European Corn Borer. NCR Publ. No. 602. Univ. of MN, St. Paul.

Padgette, S. R., N. B. Taylor, D. L. Nida, M. R. Bailey, J. MacDonald, L. R. Holden, and R. L. Fuchs. 1996. The composition of glyphosate-tolerant soybean seeds is equivalent to that of conventional soybeans. J. Nutr. 126:702-716.

Persley, G. J., and J. N. Siedow. 1999. Applications of Biotechnology to Crops; Benefits and Risks. (CAST Issue Paper Number 12.) Council for Agricultural Science and Technology, Ames, IA.

Russell, J. R., D. Farnham, R. K. Berryman, M. J. Hersom, A. Pugh, and K. Barrett. 2000a. Nutritive value of the crop residues from bt-corn hybrids and their effects on performance of grazing beef cows. Pages 56-61 *in* 2000 Beef Research Report (A.S. Leaflet R1723), Iowa State University, Ames, IA.

Russell, J. R., M. J. Hersom, A. Pugh, K. Barrett, and D. Farnham. 2000b. Effects of grazing crop residues from bt-corn hybrids on the performance of gestating beef cows. J. Anim. Sci. 78(Suppl. 2):79 .(Abstr.)

Sidhu, R. S., B. G. Hammond, R. L. Fuchs, J. 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.