CORN GENETICS AND ANIMAL FEEDING VALUE

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SUMMARY

Grain and forage from corn plants vary in composition and digestibility due to genetics and numerous environmental factors. For decades, corn hybrids have been selected based on agronomics (yield, disease and insect resistance). In addition, hybrids have been developed or selected for specific traits desired in specialty markets (food manufacturing properties: popcorn, white color, waxy, high amylose). More recently, hybrids have been screened for novel traits of either the grain (starch extractability, ethanol yield, digestibility by non-ruminants) or the forage (NDF content, NDF digestibility, lignin content). In the future, yield of biogas (methane) from different corn hybrids may become a selection criterion. Thanks to transgenics, hybrids with specific agronomic advantages (resistance to corn borers and corn rootworm; tolerance to herbicides) have been commercialized or are being developed (efficiency of nitrogen use; drought tolerance). Based on a comprehensive literature summary, no consistent differences in nutrient composition or in productivity of lactating or feedlot cattle or swine were detected between commercialized transgenic and near isogenic hybrids. With selection of hybrids for greater energy density (more lipid) or altered lipid composition, feeding value as well as certain attributes desired in animal products (altered fatty acid content; increased antioxidant concentrations; shelf life; taste) can be improved. Through altering grain density and metabolic pathways, genetic strains have been developed with increased concentrations or availability of specific nutrients or components (phosphorus; starch; protein or specific amino acids). Ideal traits for a hybrid differ among segments of the livestock or agricultural industry. Corn producers generally select hybrids based on grain yield and production cost; for livestock producers, the primary concern is feed efficiency or production per bushel or ton; for farmer-feeders, both grain yield and animal productivity must be combined in order to maximize beef or milk production per acre. To reap economic benefits from grain or silage with superior nutritional characteristics, linkage of producers directly or indirectly with livestock producers is necessary. Rapid and accurate analytical tools being developed are giving grain users the capacity to determine value more precisely. Empowering grain and silage traders and users with discriminatory power, such tools will permit livestock feeders to impose price premiums or discounts that reflect the true nutritive of the grain or silage.

BACKGROUND

Feeding value of a diet is the multiple of a) feed intake, b) concentration of the limiting nutrients or energy in the diet, and c) bioavailability (generally digestibility) of the limiting nutrient or energy. First, regarding feed intake, except when diet ingredients provide specific opiates, barbiturates, cannabis or other stimulants or addictive compounds, livestock fed properly formulated concentrate diets consume a specific number of calories. Until "nutraceutical" foods are developed, feed intake should not be altered by genetic selection or manipulation of grains or oilseeds. In contrast, for ruminants fed forage-based diets or for young pigs or poultry where diet bulkiness can limit feed intake, energy intake may be limited by bulk fill. In such cases, feed intake can be increased if fiber content is decreased or if rate or extent of fiber digestion is increased (e.g., lower lignin or NDF content). The second factor dictating feeding value, nutrient and energy concentration of cereal grains and forages, can be readily altered genetically. Regarding bioavailability, the third factor limiting feeding value, genetic selection or manipulation of cereal grains and forages can enhance availability of those nutrients or energy sources that are not already fully digested by animals.

Because seed corn is sold primarily to corn grain producers who in turn market their grain to grain elevators or brokers rather than to end-user of the crop, corn geneticists in the past have placed their greatest emphasis on traits of interest to growers, e.g., grain yield and disease resistance. With the advent of genetic manipulation of the corn plant for inherent insect control and resistance to specific herbicides, often called "input traits," additional characteristics have become important for corn geneticists to include in their hybrids. Although most corn grain producers still strive for maximum production, agronomic practices that can reduce cost of production, risk, or environmental impact (e.g., minimum tillage; inherent insect control and herbicide resistance; reduced fertilizer use) have become of increased commercial interest. With greater integration and expanding development of specialty markets for corn grain (e.g., food grade hybrids as described by Butzen and Hobbs, 2002; starch extraction for sweeteners; fermentation to produce ethanol as outlined by Butzen et al., 2003 and Haefele et al., 2004; high available energy hybrids for swine as discussed by Sauber et al., 2005), traits of value to end-users, often called "output traits," are of great commercial interest. To date most hybrid selection for these end-users has centered on screening of diverse hybrids already being produced commercially rather than on direct hybrid selection/advancement or genetic manipulation for such traits.

The objective of this paper is to provide an overview of the impact of genetic differences among commercially produced corn hybrids, both non-transgenic and transgenic, on feeding value of grain and silage. Readers must realize that feeding value alone (milk or beef per bushel or ton) does not dictate total value of a hybrid (milk or beef production per acre) due to marked differences in yield among hybrids. For example, seven different commercial hybrids were fed to steers in a trial from Nebraska (Jaeger et al., 2004). Gain to feed ratios among rolled grain from these hybrids differed by 13.5%. Based on yield tests from the same region, these seven hybrids had a range of 11.7% in grain yield. But when yield and feeding value were combined to determine which of these hybrids would produce the most beef per acre harvested, neither the hybrid with the greatest yield nor the hybrid with the greatest gain to feed ratio was ideal; instead maximum animal production per acre was achieved with a hybrid that produced near maximum yield and feed efficiency (Owens and Zinn, 2005)! For yield information, producers should consult data from nearby test plots. Also, because comparative yield can vary with to environmental conditions of a specific growing season, multi-year data on yield are preferable to information from a single year.

Table 1 lists various corn hybrid types currently being produced in the US both as commodity grain and grain for seven different specialty markets. Although these hybrid types are not mutually exclusive, the number of transgenic hybrids in the specialty categories is limited. As these data were obtained from various different sources and different years (Steward, 2003; USDA, NASS 2005; Brunoehler, 2005; USDA-Illinois Dept of Ag, 2005), values may not total 100% and acreages will change with available markets. For example, most of the grain used for ethanol production is yellow dent grain, not necessarily a hybrid designed for high ethanol yield (HTF). And if grain is not specifically produced for a market, it usually receives no price premium. Of the 52% of corn acres planted to transgenic hybrids in 2005, 26% were insect resistant, 17% were herbicide resistant, and 9% contained both traits. Of the specialty hybrids, some 57% were grown under contract with end-users. Yield drags for specialty grain for the crop produced in 2000, as estimated by the US Grains Council (2001), were 2% for white, 5% for waxy, 1% for high oil, and 8% for nutritionally enhanced grain. With specialty hybrids, growers typically are paid a premium to compensate for this yield drag and special handling and isolation, but surplus specialty grains will be fed to livestock. Information about the nutritional value of these diverse grain or silage types can provide clues useful in genetic selection of future hybrids for enhanced feeding value.

Table 1. Genetically diverse corn grain production in the U.S.

Classification	Acres in 2000, thousands	Estimated acres in 2005, thousands	Growers, % in 2005	Premium cents/bu. in 2002 survey	Premium cents/bu. in 2003 survey	Premium cents/bu. in 2005
Transgenic	14,400	32,000	50+	0	0	0
Hard or Food	1,375	1,250	19	15	19	8.5
White	925	1,000	12	30	33	20
Waxy	550	485	9	27.5	30	20
High extractable starch (HES)	0	300	-	9.5	-	12.5
High fermentable starch (HTF)	0	250	4	-	11	5
Nutritionally Enhanced	225	115	9	27	18	25
High amylose	45	50	-	110	-	220
High oil	750	?	-	27.5	-	12+
Organic	?	?	4	-	98	500+
Non-GMO	65,600	31,000	50	9.5	-	6.5

CORN GRAIN: GENETIC TYPES AND FEEDING VALUES.

The impact of corn grain characteristics on feeding value has been reviewed for dairy cattle by Dado (1999) and for beef cattle by Stock (1999). In addition, specific grain components potentially limiting digestion and the impact of processing have been reviewed by Owens and Zinn (2005). Trials examining the effects of transgenically altered grain and silage on feeding value have been enumerated by the Agricultural Biotechnological Stewardship Technical Committee (2000) and by FASS (2005), evaluated by Clark and Ipharraguerre (2001), and are updated below. Recommended practices for conducting animal trials to evaluate genetically altered crops have been compiled in a 70-page text published by ILSI (2003). Additional discussion related to safety and marketing of transgenic crops have been provided by Beever and Kemp (2000) and by Welge and Morantes (1998) and will not be covered in this paper.

Transgenic alterations. Corn hybrids transgenically altered for insect protection and herbicide tolerance are grown widely in the US on a continually expanding acreage. Insects of major concern have been various corn borers and corn rootworms. Incorporation of specific genes from Bacillus thuringiensis will confer plants with inherent insect (lepidoptera) protection; hybrids carrying this trait often are called "Bt" as a shorthand notation for the bacteria from which the gene was isolated. Not all Bt hybrids are the same; instead, the trait has been incorporated into hybrids based on different "events" as noted in Table 2. Not only does relative efficacy differ among these events, but distribution of the endotoxin in various portions of the corn plant also will vary. Corn rootworm (coleoptera) protection is achieved through separate events as shown in Table 2. Herbicide resistance, the third input trait of widespread interest, permits broad-spectrum herbicides to be used for weed control. Some hybrids today contain two or all three of these traits "stacked" within the same hybrid.

Table 2. Traits, transgenic events, and commercial sources of modified corn.

Trait	Event	Commercial Sources	Delta endotoxin
Corn borer resistance	176	KnockOut (Novartis), NatureGard (Mycogen)	Bt - Cry 1A(b)
Corn borer resistance	Bt11	YieldGard (Syngenta)	Bt - Cry 1A(b)
Corn borer resistance	Mon810	YieldGard (Monsanto - marketed by DeKalb, Golden Harvest, Pioneer, and others)	Bt - Cry 1A(b)
Corn borer resistance	DBT418	Bt-Xtra (DeKalb)	Bt - Cry 1A(c)
Corn borer resistance	CBH351	StarLink (Aventis)	Bt - Cry 9C
Corn borer resistance and Glufosinate tolerance	TC1507	Herculex 1 (Mycogen, Pioneer)	Bt - Cry1F, Stretpomyces
Corn rootworm resistance	MON863	MaxGard (Monsanto)	Bt - Cry3Bb
Corn rootworm resistance	149B1	Herculex Rootworm (Mycogen, Pioneer)	Bt - Cry 34Ab1, Bt – Cry 35Ab1
Glyphosate tolerance	GA21	Roundup Ready (Monsanto and DeKalb)	Zea mays
Glyphoshate tolerance	NK603	Roundup Ready (Monsanto)	Agrobacterium; Arabidopsis
Glyphosate tolerance	MON802	Roundup Ready (Monsanto)	Agrobacterium; Bt; Achronobacter
Glufosinate tolerance	T14; T45	Liberty Link (AgrEvo)	Streptomyces
Glufosinate tolerance	B16	Liberty Link (DeKalb)	Modified Streptomyces
Glufosinate tolerance	676, 678, 680	Liberty Link and Male Sterile (Pioneer)	E coli, Streptomyces
Glufosinate tolerance	MS6	Liberty Link and Male Sterile (AgrEvo)	Bacillis, Streptomyces

Because the primary targets for these genetic alterations have been insect and herbicide resistance and because the inserted genes should not alter nutrient composition (and hence the feeding value of the crop), nutrient content and nutritional value should be similar for biotech crops and non-biotech crops. Nevertheless, transgenic crops are widely studied by developers and by regulatory agencies to determine if they are "substantially equivalent" in nutrient composition to 1) the crop not carrying the gene (the "near-isogenic" hybrid) and 2) commercial hybrids grown under similar environmental conditions. Extensive chemical analysis and toxicity studies have been conducted to assure that biotech crops have equivalent nutritive value both for regulatory agencies and for crop users. Following clearance and release of a new trait, independent "stewardship" trials, often supported by seed companies, are conducted to further appraise the nutritional value of grain or silage carrying the trait for end users. However, nutritional comparisons of a transgenic hybrid with its near-isogenic counterpart can be imprecise. This is because 1) insect or disease pressures on the unprotected crop can alter composition or mycotoxin presence, 2) herbicide or pesticide residues may remain on control or the "near-isogenic" hybrid and these may alter livestock performance, and 3) field, harvest, or feeding conditions can never be identical for two hybrids used in a comparison.

Nutrient composition. To determine whether a transgenic hybrid is "substantially equivalent" to the non-transformed crop or commercial hybrids, grain or forage samples are subjected to numerous chemical assays; results are appraised by governmental agencies (USDA, FDA, EPA). To date, 29 independent studies, enumerated individually at the end of this paper, have been published which have examined the chemical composition of transgenic grain and silage being fed in trials with ruminants and swine. A summary of composition comparisons from studies comparing transgenic grain or silage to its near isogenic hybrid is presented in Table 1. Note that among the 63 specific comparisons, only 4 significant differences in nutrient composition were detected. In one trial with lactating cows and three trials with corn stalk residues, significant differences between the Bt hybrid and its isogenic hybrid were detected. Based on a statistical probability of 5%, one would expect to detect 3 differences due merely due to statistical chance! For in vitro dry matter digestibility, the value for transgenic cornstalks was increased in two studies but decreased in the third! The lack of consistent and significant composition differences would support the contention that the insertion of genes in the events tested did not alter nutrient composition of corn grain or corn silage. In one large field survey, Faust (1999) indicated that dry matter content of silage was greater for Bt hybrids than for "typical" hybrids, possibly due to reduced insect damage. Lignin concentration of silage was reported to be elevated in Bt hybrids according to one report (Saxena and Stotzky, 2001), but this finding subsequently was refuted by comparison of multiple hybrids grown at several locations (Jung and Schaeffer, 2004) based on multiple methods of lignin analysis.

The comparisons summarized in Table 3 are based on repeated nutrient assays for samples typically of a specific transgenic and near-isogenic hybrid. To determine the impact of these transgenic events across various hybrids, data from these same trials were analyzed further using the nutrient concentrations provided by authors. This further tests the consistency of transgenic events on nutrient composition across hybrids. Results are presented in Table 4. Again, no consistent differences in nutrient composition were detected between grains or forage from genetically transformed versus that from the near-isogenic hybrid or unrelated "control" hybrids.

Table 3. Literature summary of statistical differences in nutrient composition comparing transgenic corn with its near isogenic counterpart. For trials where a significant increase (+) or decrease (-) was detected, the type of transgenic alteration and percentage change from its near isogenic hybrid are noted.

Measurement	No significant difference	Significant increase	Significant decrease	Lactating cows fed silage	Lactating cows fed grain	Steers fed silage	Steers fed grain	Steers fed stalks	Pigs fed grain
Composition									
Dry matter	14	0	0						
Crude protein	19	1	0	Bt+10.8					
Starch	5	0	0						
NDF	16	0	0						
Lignin	6	0	0						
Ash	8	0	0						
Fat	5	0	0						
NDFD	3	0	0						
IVDMD	7	2	1					Bt-8.4 Bt+15.0 Bt+14.7	

Table 4. Grain compositions of corn borer protected (Bt), Roundup-Ready (RR), and corn rootworm (CRM) hybrids compared with near isogenic (I) or additional non-transgenic control hybrids, percentage of DM.

Type or Contrast	Bt	Isogenic	Bt vs I Prob =	RR	Isogenic	Control	RR vs I Prob =	RR vs C Prob =	CRW	Isogenic	Control	CRW vs I Prob =	CRW vs C Prob =
Trials	13	13		11	11	11			6	6	6		
DM	86.0	86.0	-	87.3	87.2	86.9	0.85	0.56	90.4	90.2	89.9	0.80	0.52
CP	7.78	7.91	0.41	8.69	8.78	8.99	0.81	0.39	9.60	8.70	8.95	0.32	0.37
NDF	9.2	10.1	0.20	8.9	9.0	9.0	0.68	0.74	10.1	8.0	8.4	0.12	0.13
Lignin	-	-	-	1.30	1.35	1.20	0.71	0.41	1.40	1.10	1.05	0.50	0.41
Ash	-	-	-	3.31	3.63	3.32	0.08	0.99	1.50	1.40	1.45	0.50	0.67
Fat	-	-	-	4.11	4.06	4.19	0.86	0.80	4.00	4.20	3.95	0.92	0.97
Starch	-	-	-	77.0	77.4	77.1	0.68	0.85	74.0	77.6	76.7	0.30	0.33

Nutritional value. Even though two similar feeds that are nearly identical in nutrient composition would be expected to have similar nutritional value, numerous feeding trials have been conducted to appraise feeding value of transgenic grain and silage. A summary of those trials is presented in Table 5. Results were compiled across all transgenic grain and silage samples fed to lactating cows, feedlot cattle, and pigs. The literature references for these feeding trials are noted in the numbered reference list. Among the 188 animal contrasts, significant differences ($P < 0.05$) were detected in 14 (7%) of the comparisons.

In four of 39 trials, larger amounts of silage or grain were consumed when obtained from Bt hybrids. This may reflect indirect effects of Bt on composition, e.g., infestation of the non-Bt product with fungi that produce mycotoxins (Munkvold et al., 1999; Dowd, 2000) associated with plant damage by insects. In two of 32 trials, daily gain was greater for steers receiving Bt hybrids. However, in three out of 33 reports, gain to feed ratio by steers was lower with the Bt hybrid than with its near isogenic counterpart. Milk production was lower for cows fed silage from a herbicide resistance hybrid in one study, but the authors attributed this difference to higher dry matter content (37 versus 32% dry matter) and the lower feed intake by lactating cows fed silage from the herbicide-resistant hybrid. Based on this overview, production by animals fed silage or grain with Bt or the herbicide resistance traits was not consistently different from that of animals fed the hybrid without these traits.

Again, to further examine the absolute magnitude and consistency of animal response to specific traits across hybrids, performance responses from individual experiments were combined from experiments where the reference included numerical data. Performance responses averaged across experiments with pigs, steers, and cows fed silage or grain from hybrids with the Bt trait as compared with its near-isogenic hybrid or with or additional unrelated hybrids fed in the same trial are presented in Table 6. No consistent impact of the Bt trait on performance of swine, feedlot cattle, or lactating dairy cows was detected.

Least squares means reflecting consistency of animal responses across feeding trials to the Roundup Ready trait are presented in Table 7. Again, no consistent response in nutritive value to this trait was apparent based on means provided in these literature reports.

Least squares means reflecting consistency of animal responses across feeding trials to resistance to corn rootworm are presented in Table 8. Although the number of feeding trials with this trait is limited, no consistent differences in animal performance associated with the transgenic trait were detected.

Based on results from these trials published by numerous authors, these transgenic traits had no consistent impact on productivity of pigs or cattle. Considering the similarity in nutrient composition of the transgenic crop with its near isogenic counterpart, it would be surprising to detect a difference in animal performance! Nevertheless, in some of these trials, differences among the control non-transgenic hybrids being fed were detected. This reflects diversity in nutrient composition among non-transgenic hybrids being grown commercially today.

Table 5. Literature summary of statistical differences observed with transgenic corn versus its near isogenic counterpart. For feeding or lactation trials where a significant increase or decrease was detected, the type of transgenic alteration, the percentage change from its near isogenic hybrid (or its control hybrid when an isogenic hybrid was not fed), and the number of the reference in the literature cited list is noted.

Measurement	No significant difference	Significant increase	Significant decrease	Lactating cows fed silage	Lactating cows fed grain	Steers fed silage	Steers fed grain	Steers fed stalks	Pigs fed grain
DM Intake	34	4	1	Bt+5.8 (1) RR-10.9 (21)		CRW+2.9 (41)	Bt+3.4 (17) Bt+3.5 (17)		
Daily gain	29	2	1			Bt+7.4 (17) Bt-3.6 (17)			Bt+5.6 (32)
Gain/feed ratio	27	0	3			Bt-7.0 (17) Bt-5.5 (23)	Bt-4.6 (31)		
Marbling score	10	0	0						
Ribeye area	17	0	0						
Fat thickness	16	0	1						Bt-7.4 (44)
Yield grade	10	0	0						
FC Milk	10	0	1	RR-9.0 (21)					
Milk fat %	11	0	0						
Milk protein %	10	1	0	Bt+3.0 (6)					

Table 6. Animal performance responses to transgenic corn grain with the Bt trait.

Swine performance	Bt	Isogenic	Control	Bt vs I Prob =	Bt vs C Prob =
Trials	4	4	7		
Daily DM intake, kg	1.67	1.69	1.66	0.59	0.66
Daily gain, kg	0.875	0.879	0.882	0.58	0.49
Gain/Feed	0.378	0.376	0.380	0.81	0.80
Rib eye area, cm^2	50.2	49.0	51.1	-	-
Fat thickness, cm	1.98	2.18	2.01	-	-
OM digestibility, %	87.70	88.10	87.20	0.72	0.61
Steer performance	**Bt**	**Isogenic**	**Control**	**Bt vs I Prob =**	**Bt vs C Prob =**
Trials	5	5			-
Daily DM intake, kg	9.66	9.75	-		-
Daily gain, kg	1.43	1.48	-	0.16	-
Gain/feed	0.149	0.152	-	0.62	-
	Transgenic silage & grain				
Lactating cow performance	**Bt**	**Isogenic**	**Control**	**Bt vs I Prob =**	**Bt vs C Prob =**
Trials	6	6			
Daily DM intake, kg	24.2	24.3	-	0.96	-
FC Milk, kg/day	34.1	33.2	-	0.11	-
Fat, % of milk	3.63	3.59	-	0.35	-
Protein, % of milk	3.14	3.12	-	0.43	-

Table 7. Animal performance responses to transgenic corn grain with the Roundup Ready trait.

Swine performance	**RR**	**Isogenic**	**Control**	**RR vs I Prob =**	**RR vs C Prob =**
Trials	4	3	4		
Daily DM intake, kg	2.42	2.45	2.43	0.47	0.82
Daily gain, kg	0.932	0.926	0.938	0.70	0.75
Gain/Feed	0.386	0.374	0.387	0.15	0.81
Rib eye area, cm^2	49.4	50.6	49.4	0.27	0.98
Fat thickness, cm	2.51	2.44	2.44	0.14	0.11
Steer performance	**RR**	**Isogenic**	**Control**	**RR vs I Prob =**	**RR vs C Prob =**
Trials	6	6	10		
Daily DM intake, kg	10.37	10.42	10.44	0.90	0.85
Daily gain, kg	1.64	1.71	1.67	0.32	0.67
Gain/Feed	0.157	0.164	0.158	0.04	0.60
Rib eye area, cm^2	86.1	88.3	87.1	0.32	0.60
Fat thickness, cm	1.33	1.33	1.33	0.99	0.98
Yield grade	2.65	2.52	2.42	0.52	0.21
Marbling score	539	537	534	0.94	0.75
	Transgenic silage & grain				
Lactating cow performance	**RR**	**Isogenic**	**Control**	**RR vs I Prob =**	**RR vs C Prob =**
Trials	4	3	5		
Daily DM intake, kg	23.2	24.1	24.7	0.31	0.14
FC Milk, kg/day	30.7	32.0	33.6	0.45	0.24
Fat, % of milk	3.74	3.74	3.76	1.00	0.74
Protein, % of milk	3.14	3.17	3.16	0.31	0.64

Table 8. Animal performance responses to transgenic corn grain with resistance to corn rootworm.

Swine performance	**CRW**	**Isogenic**	**Control**	**CRW vs I Prob =**	**CRW vs C Prob =**
Trials	3	3	2		
Daily DM intake, kg	2.60	2.41	2.50	0.25	0.39
Daily gain, kg	0.860	0.860	0.900	1.00	0.26
Gain/Feed	0.340	0.360	0.360	0.50	0.45

Steer performance	**CRW**	**Isogenic**	**Control**	**CRW vs I Prob =**	**CRW vs C Prob =**
Trials	2	2	4		
Daily DM intake, kg	10.26	10.16	10.21	0.77	0.85
Daily gain, kg	1.87	1.83	1.80	0.60	0.27
Gain/Feed	0.185	0.182	0.179	0.71	0.32
Rib eye area, cm^2	91.8	89.7	91.3	0.19	0.66
Fat thickness, cm	1.07	1.13	1.06	0.19	0.66
Yield grade	2.10	2.30	1.90	-	-

	Transgenic grain only				
Lactating cow performance	**CRW**	**Isogenic**	**Control**	**CRW vs I Prob =**	**CRW vs C Prob =**
Trials	1	1	2		
Daily DM intake, kg	27.3	26.6	26.2	0.26	0.14
FC Milk, kg/day	35.1	35.0	34.6	0.93	0.60
Fat, % of milk	3.75	3.56	3.69	0.25	0.54
Protein, % of milk	3.18	3.19	3.18	0.50	0.67

Corn Grain Specialty Hybrids

Characteristics and management of specialty or value-enhanced grains as well as production economics have been described in publications from the US Grains Council (2001), Steward (2003), the Illinois Council on Food and Agricultural Research (2003), and Hough (2005).

Hard Endosperm or Food Grade Corn. Corn kernels vary from soft (floury) to hard (vitreous) due to genetic and environmental conditions. Most food manufacturers prefer vitreous hybrids, typically those hybrids that have a high bushel weight, for producing appropriately pigmented (white or yellow) chips, grits, and four. Within corn kernels from commercial yellow dent hybrids, from 25 to 80% of the starch will be present as horny (hard or vitreous) endosperm where starch granules are densely packed within a protein matrix. The remaining starch, like starch present in most other cereal grains (barley, oats, wheat) is deposited as floury or soft starch. Microscopically, the floury starch resembles basketballs held in a large mesh bag by endosperm cell walls. Vitreousness can be determined through physical dissection of kernels, by measuring absolute density (not test weight) of the grain, by grinding with a Stenvert mill, or by near-infra red reflectance. The horny to floury ratio (H:F) is greater for corn grain classified as flint (versus dent) grain and usually increases with grain maturation and nitrogen fertility (that also can increase crude protein content of corn grain). Based on ruminal incubation of feed samples in Dacron bags (in situ procedures), starch loss from ground corn grain is less rapid for hybrids that have a high H:F ratio (Phillippeau and Michalet-Doreau, 1997; Phillippeau et al, 1999; Shaver and Majee, 2002). This has led to the suggestion that ruminal digestion is greater for hybrids with more floury starch. Close examination of Dacron bag disappearance curves from these studies reveals that virtually all of the increased in situ loss for the floury hybrids is lost even before fermentation begins (wash loss). Indeed, floury hybrids generate more fines during grinding, and fine particles readily slip through pores in Dacron bags. The nutritive merit of fine particles can vary depending on the diet. Higher total tract digestibility of small versus large particles should be beneficial, and some fine and dense particles will be flushed rapidly through the rumen with fluids to increase the starch supply to the intestines. However, because they are fermented very rapidly in the rumen, fine particles from the floury endosperm can increase the risk of acidosis.

Greater in situ disappearance of floury hybrids has led to the suggestion that extent of ruminal digestion will be greater for a floury than a vitreous hybrids when the grain is <u>dry rolled</u> through a mill at a standard setting (not extensively processed). This concept was verified with dry rolled corn by Jaeger et al. (2004); they observed that hybrids with more floury starch produced the best gain efficiency (r = 0.83). Similarly, floury starch from grain was more extensively digested by lactating cows in the rumen (Ying and Allen, 2005), and Fanning et al. (2002) noted that total tract digestion of starch from corn silage by lactating cows was greater for a hybrid with floury endosperm than a hybrid with a vitreous endosperm whether or not the silage had been kernel processed. Despite efficiency and starch digestibility increases, no differences in rate of gain (Jaeger et al., 2004) or in milk production or components has been detected between these two endosperm types (Longuski et al., 2002). A low H:F ratio can complicate grain processing. When being flaked, floury hybrids generate fragile flakes and more fine particles; they also tend to flake more slowly than more vitreous hybrids. Fermentation also will alter vitreousness of grain. Kernels in fermented corn silage were less vitreous than corn kernels at harvest (Johnson et al., 2002). When high moisture corn was prepared from a vitreous and a floury corn hybrid, digestibility of starch both in the rumen and the total digestive tract surprisingly tended to be superior for the vitreous hybrid, possibly due to greater fracture of the more vitreous kernels during grinding prior of wet grain prior to ensiling (Josh Szasz, personal communication). In summary, compared with more vitreous or flint hybrids, floury dent hybrids are more extensively digested by ruminants when processed simply through being coarsely rolled. However, this starch digestibility advantage for more floury hybrids is NOT apparent for corn grain that is processed for ruminants by other methods (steam rolled or flaked or fermented alone or in corn silage) or when grain is finely ground for feeding to swine or poultry.

<u>Waxy hybrids.</u> Chemically, starch exists in two forms: amylopectin, a multi-branched structure, and amylose, a linear structure that is more slowly digested by enzymes. Amylose can comprise from below 2% (waxy corn) to 90% (high amylose) of total starch due to genetic differences in activity of the amylose extending gene and enzyme. Due to characteristics of the isolated starch, wet millers process waxy corn to produce starches for industrial and food markets; in contrast, starch from high amylose corn is used in adhesives, candies, textiles, and dietetics. Besides being genetically determined, environmental factors can alter amylose synthesis in some plants. Of the starch in typical dent corn hybrids, some 24 to 30% is amylose with floury starch being 4 to 9 units greater in amylose than vitreous starch. The amylose to amylopectin ratio increases with corn kernel maturity but can be decreased by high environmental temperatures. Waxy

sorghums have considerably higher feeding value than normal sorghums (Rooney et al., 1986), but value of waxy corn for ruminants will vary with processing method. Relative to starch from normal or waxy hybrids, starch from high amylose hybrids is slowly digested by either ruminal microbes or intestinal enzymes. Indeed, high amylose starch is finding application in human medicine both to retard blood glucose spikes after a meal for diabetics and to increase starch flow to the large intestine that may reduce the incidence of colon cancer. Corn grain with a higher amylose content was poorly digested in the small intestine of dogs even after the grain had been extruded (Gajda et al., 2005). Susceptibility of flaked high amylose corn samples to ruminal digestion also is low, perhaps because fermentation of amylose appears restricted to a limited number of bacterial strains (Wang et al., 1999). As individual starch granules consist of consecutive rings or spheres of amylose and amylopectin, retarded amylose degradation may limit enzymatic accessibility of starch within starch granules. Because total tract digestibility of starch normally exceeds 98% for nonruminants fed typical ground corn and for ruminants fed flaked or high moisture corn, disruption of starch granules by fine grinding or processing must alter or solubilize amylose to the point that it is either fermented or digested. In support of this concept, flaking removed the feed efficiency advantage of waxy (low amylose) hybrids over typical hybrids (normal amylose) often noted with dry rolled grains in steer performance trials (Owens and Zinn, 2005). To date, analysis of the amylose to amylopectin ratio of duodenal, ileal, and fecal samples has not been reported; such information should help quantify the importance of amylose content on site and extent of starch digestion by cattle fed grain subjected to different processing methods.

High extractable starch (HES). During the wet milling process, an average of 66% of starch from typical corn grain is extracted; with high extractable starch hybrids, up to 72% can be extracted readily, largely due to differences in genetics. Rapid NIR procedures for predicting extractability have been developed and are being used currently. Failure to fully extract starch appears related to tight adhesion of starch to the pericarp. Although no direct relationship of starch extractability to feeding value has been detected, postruminal digestion of starch from dry rolled corn was significantly correlated with starch extractability in one trial. Because starch is more digestible than most other grain components (fiber, protein) but not oil, grain with a higher ratio of starch to protein or fiber will provide more digestible energy for animal use.

High fermentable starch (HFS). Ethanol yield per bushel of corn fermented varies by as much as 7% among individual hybrids. Commercial trials at dry grind ethanol plants indicate that batches of grain segregated using NIR procedures for high HFS produced an average of 4% more ethanol than unselected grain. The fact that waxy hybrids typically have high ethanol yields suggests that starch type or accessibility may limit ethanol yield per unit of time. No relationship of HFS ranking to feeding value for pigs or cattle has been detected to date.

Nutritionally enhanced corn. Hybrids containing more protein (often over 10%) and oil (often over 5.5%) are being marketed as being "nutritionally enhanced grain." High oil top-cross corn also fits into this category. Some hybrids (Dow's Supercede and ExSeed's NutriDense) also have elevated amino acid concentrations; additional discounts (for foreign matter, kernel damage, low test weight, and high moisture) for components that may reduce feeding value have been proposed for nutritionally enhanced grain. Unfortunately, sub-optimal yield and agronomics as well as identity preservation costs have hindered widespread acceptance of nutritionally enhanced corn. Because benefits from enhanced amino acid concentrations and elevated lipid content will vary with animal species and ingredient costs, value of nutritionally enhanced corn will vary with its market. Consequently, subdividing this category and developing hybrids regionally or locally for specific target species would be expected.

High available energy (HAE). Based on measurements of digestible and metabolizable energy content for pigs of nearly 200 corn grain hybrids, NIR (near infra-red) prediction equations were developed by Pioneer, a DuPont Company (Sauber et al., 2005). Based on NIR scans, commercially marketed Pioneer hybrids with high digestibility now are being classified as HAE hybrids. Although those hybrids with high oil and low fiber content generally have greater digestibility, additional factors related to digestibility of fiber and protein also appear important for this classification. Although the predictability applies for both poultry and swine, hybrids with high HAE values do not appear to have increased ruminal or total tract digestibility values for ruminants. Certainly, fine grinding of grain for feeding nonruminants removes some of the barriers that limit digestion by ruminants. Whether more extensive processing (high moisture fermentation; flaking; extrusion; pelleting) that can physically and chemically grain will impact HAE ranking of hybrids is not known.

CORN SILAGE: GENETIC TYPES AND FEEDING VALUES.

Over the past 75 years, dry matter yield of both corn stover (corn plant minus the ear) and whole corn plants have increased markedly. Due to selection of hybrids for high grain yield, grain yield has increased more than stover yield so that grain content of corn silage today often exceeds 55% of dry weight and grain can provide over 75% of the digestible energy of corn silage. Fortunately, fiber digestibility is not genetically related to grain yield (Coors, 1996; Buxton et al., 1996). Weiss (2001; 2004) has outlined the merits of different non-transgenic corn hybrids and their nutritional value. As with grain, the primary factors influencing feeding value of corn silage are 1) feed intake, 2) nutrient composition, and 3) nutrient digestibility. Digestibility of a diet ingredient depends on concentration and the digestibility of the individual components that comprise that ingredient. Both genetics and environmental factors associated with crop production can influence the nutrient content of grain or silage; composition together with feed processing and feeding management can alter site and extent of digestion. Relative feeding values for silages produced from corn hybrids selected for specific traits have been reviewed by Hutjens (2000), Weiss (2001) and Mahanna and Peterson (2004).

Compared to grain, silage is much more variable in chemical composition due to wide differences in the ratio of grain to stover. Maturity at harvest further complicates this relationship; sugars and other nutrients initially deposited within the stalk and leaves are gradually translocated for deposition in the ear. Reflecting this transfer, some trials indicate that stover dry weight and total stover NDF yield both will decrease as silage harvest is delayed and grain fill increases. Combined with an increase in grain content, changes during maturation drastically complicate the interpretation of digestion measurements and direct comparison among various hybrid types. Because digestibility of starch always exceeds digestibility of fiber, selection for high grain yield is important. Grain yield and total silage yield generally are well correlated. But even within high yielding hybrids, fiber digestibility will vary (Buxton et al., 1996). Although feeding value must be balanced against total yield (tonnage), corn silage hybrids with greater feeding value (intake; digestibility) have been identified. Numerous factors related to silage management (harvest date; harvest height; packing for air exclusion; removal rate; aerobic stability) can impact feed intake and digestibility. Conditions on a specific farm (availability and cost of other sources of NDF and grain byproducts; cost and management of purchasing supplemental grain; tillable acres, crop rotations, and storage space) can alter preference for a hybrid further. Some nutritionists recently have promoted the concept of coordinating ruminal digestion rates of silage with grain. By reducing starch content of silage or alerting its starch type and providing supplemental grain of a specific type or especially processed, they propose that milk production can be increased (Beck, 2003). However, economics must be considered. It seems highly unlikely that purchasing and importing grain to a farm to supplement a corn silage selected to be low in grain content (and thereby often low in tonnage) will prove economically wise. As grain yields and ratio of grain to stover continue to increase, the amount of grain that needs to be include in corn silage-based diets will continue to decrease. This change as well as yearly variation in starch content of corn silage as well as increasing starch availability with longer fermentation times will require increased attention both in diet formulation and in total farm management, e.g., allocating available acres to specific crops.

Transgenic hybrids. As discussed above, review of published literature has detected no consistent difference in feed intake or chemical composition of silages associated with genetic alteration to resist insects or tolerate herbicides (Tables 3 and 4). Similarly, no differences in performance (milk yield or milk composition between from lactating cows fed silage; gain and efficiency of steers fed high silage diets) from transgenic and the near-isogenic or non-transgenic hybrids have been detected (Tables 5 through 8). Indirect effects associated with reduced insect damage of Bt hybrids (greater carotene and moisture retention; lower mycotoxin concentrations) have been detected in some studies where insect damage was evident (Faust, 1998).

Specialty corn silage hybrids. Differences in chemical composition between silages produced from hybrids selected for grain yield versus brown midrib (BMR) and leafy hybrids are summarized in Table 9.

Table 9. Chemical composition of various specialty corn silages based on paired comparisons from published research trials

Item	**High grain**	**Brown mid-rib**	**Leafy**
Crude protein	7.7	8.1	7.9
Starch	30.1[a]	29.5[ab]	28[b]
NDF	43[b]	41.9[b]	45.1[a]
Cellulose	22.2[b]	22[b]	23.4[a]
Lignin	2.75[a]	1.82[b]	2.77[a]
IVDDM	74.8[b]	80.4[a]	75.7[b]
NDFD	42.6[c]	52.7[ab]	46.4[b]

Brown midrib hybrids. As noted in Table 7 and in previous comparisons (Eastridge, 1999), lignin content is markedly lower whereas NDF digestion in vitro (NDFD) and in situ is greater for BMR hybrids than for hybrids selected for grain yield. An increased NDFD at 30 or 48 hours of incubation and lower lignin content consistently have increased feed intake by lactating cows. This conclusion, as illustrated in Figure 1, is based on 18 comparison over the last 6 years published in the Journal of Dairy Science (Akay and Jackson, 2001; Bal et al., 2000a, 2000b;

Ballard et al., 2001; Cooke and Bernard, 2005; Ebling and Kung, 2004; Greenfield et al., 2001; Ivan et al., 2005; Kuehn et al., 1999; Nennich et al., 2003; Neylon and Kung, 2003; Oba and Allen, 1999, 2000a, 2000b; Taylor and Allen, 2005a, 2005b; Thomas et al., 2001; Tine et al., 2001; Weiss and Wyatt, 2002).

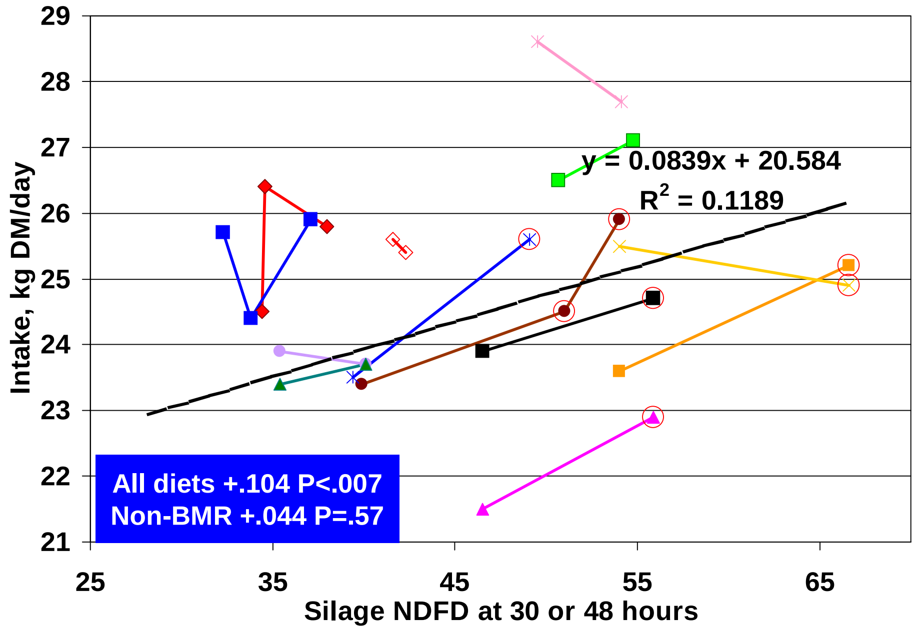

Figure 1. Intake of corn silage-based diets with different extents of NDF digestion. Lines connect points within a trial with circled values representing results with BMR hybrids.

The increased feed intake has been most evident with the large increases in NDFD as seen with BMR silages. In previous reviews, an increase in NDFD of 1% has increased daily feed intake by 0.17 kg (Oba and Allen, 1999 across a wide variety of diets) and 0.12 kg (Jung et al., 2004 with corn silage diets) as compared with the 0.10 kg in this review. For every kg increase in feed intake, about 1 kg more milk is produced. Consequently, for every 1% increase in NDFD, daily milk production was increased by 0.25 kg (Oba and Allen, 1999), by 0.15 kg (Jung et al., 2004) and by 0.14 kg in this review. This increase feed intake can explain at least 70% of the increase in milk production. Presumably, feed intake increases because of faster ruminal digestion and clearance. Surprisingly, total tract digestibility of various diet components (NDF, organic matter, protein, starch) is NOT increased in parallel with the increase in vitro NDF digestibility. Indeed, the increases in dry matter intake have been more closely correlated with corn silage lignin content than with corn silage NDFD (P = 0.0001 vs 0.002). Furthermore, intake increases were NOT correlated with total dietary lignin or dietary NDF concentrations, only with these components in corn silage. Perhaps the higher intake associated with low corn silage lignin content is due to factors beyond passage rate (differences in distribution of fibrous components of the stover; microbial inhibitors released from silage lignin). As composition and digestibility of BMR hybrids appears similar to that of conventional hybrids, the increased milk production must be balanced against the increased feed intake and lower silage yields (about 10% with a range of 3 to 17%) associated with field lodging of current BMR corn silages (Eastridge, 1999;

Weiss, 2001). Because lignin and NDF content of the stalk is highest in the lowest section of the corn stalk, leaving more stubble in the field (setting the chopper high) will decrease lignin and NDF content of silage. Summarizing 11 cutting height studies, Wu and Roth (2003) indicated that increasing corn silage chop height from 7 to 19 inches decreased silage NDF by 7% and increased in vitro NDF digestibility by 4.7% (54 versus 50.6%). However, harvested tonnage was reduced by 7.4%. They suggested that increasing harvest height by 12 inches would increase milk per ton an average of 5.2% but decrease milk per acre by 1.7%.

Leafy or high NDF corn silage hybrids. With more leaves above the ear, leafy hybrids have a slightly higher percentage of dry matter as leaves (13% vs 11%; Kuehn et al., 1999). As noted in Table 9, leafy hybrids have less starch but more NDF and cellulose than conventional hybrids selected for grain yield. In vitro NDF digestion also appears greater. This might be expected, because in vitro dry matter digestibility is greater and more constant for leaves than for stems (an average of 63% for leaves versus 62 to 47% for stems with values dropping as the stems mature from silking to physiological maturity; Lundvall et al., 1994). Yet, considering the small difference in leaf yield and the decreased grain yield, feeding value of leafy hybrids has not been significantly different from conventional hybrids (Weiss, 2001). Only when other sources of NDF are costly or are not available for a livestock operation would selection of a silage hybrid high in NDF content silages prove economical in a properly formulated dairy diet.

<u>High oil or Energy Dense corn silage hybrids.</u> Although hybrids selected for increased oil content have more oil in the grain, oil content of the stover of top-cross high oil hybrids is not increased. Nevertheless, high oil corn silage has reported to have up to 5% greater digestible energy. Both high oil and energy dense grain also will have slightly more protein than conventional corn silage. High oil and protein content gives such hybrids an increased feeding value that may compensate for the differences in seed and production (isolation) costs and yield. The relative cost and convenience of other oil sources that can be supplemented also must be considered.

<u>Waxy and floury grain corn silage hybrids.</u> For dry rolled grain, starch digestibility typically is greater for floury (than vitreous) and for waxy (than higher amylose) hybrids. This observation has led to the concept that corn silage produced from such hybrids would have greater starch digestibility. However, considering the immaturity of grain when harvested as corn silage (before vitreousness increases markedly), the fermentation associated with ensiling (solubilization of protein in the grain), and particularly "kernel processing" of corn silage (to increase exposure of starch for digestion), advantages in starch digestibility of floury or waxy silages appear small except when the crop is harvested at a very mature stage. Furthermore, milk production responses to silage from waxy or floury grain types have been minimal, partly due to the limited contribution of starch from corn silage to the total mixed diet typically fed to dairy cows. With diets very rich in corn silage, with more mature and unprocessed silage, and with further increases in the grain to stover ratio, kernel hardness and starch type would be of greater concern.

FUTURE IMPACTS OF CORN GENETICS

Additional grain and silage production traits currently under study include alterations to increase drought tolerance, to enhance efficiency of use of nitrogen, and to improve disease and mycotoxin resistance. Grain and silage quality traits of active research interest include protein modifications (elevated lysine and methionine concentrations and greater protein digestibility), fiber (increased rate of digestion and lower lignin content), starch (higher digestibility), lipid (increased content and altered fatty acid composition), and minerals (elevated bioavailability) as described by Hard (2005) and Hartnell et al. (2005). Rapid techniques can be used for immediate recognition of corn hybrids or corn samples with superior value for starch extraction, for ethanol production, and in feeding value for swine; near infra-red (NIR) scanning procedures have been developed by grain scientists for grain users to employ when selecting hybrids or grain batches for high extractable starch (HES), high total fermentables (HTF), and high available energy (HAE), respectively. Such procedures are being employed seed companies to classify hybrids, by plant breeders for selecting hybrids for specific end-users, and by some grain users to assign price premiums or discounts to batches of grain. By encouraging production of specific hybrids for specific markets, such procedures are further challenging the "commodity" trading of grain. Hybrids with insect and herbicide resistance as well as those with improved bioavailability of nutrients are improving the efficiency of both plant and animal production. In addition, through reducing the widespread use of chemicals (pesticides, herbicides) as well as the quantity of undesirable nutrients excreted in animal wastes, new hybrids hold strong promise to further reduce the environmental footprint of both plant and animal production.

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