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Developing New Specialty Grains for Ruminants

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SUMMARY

Corn, soybean, and sunflower hybrids with improved agronomic and nutritional traits are grown widely today. Barring increased concern about genetically altered crops, production of specialty grains is likely to increase because novel traits possessed by many new hybrids are desired by both grain producers and grain users. Most specialty grains available today possess improved altered "input traits" that enhance either agronomic or production characteristics. More recently, hybrids with enhanced "output traits," with increased value for specific users (millers, brewers, starch or oil extractors, livestock feeders), have been developed and are being released. Grain growers readily adopt varieties with improved input traits (insect or herbicide resistance) when they have an assured grain market. In contrast, grain with improved output traits usually does not increase yield or reduce input cost for the grain growers. Indeed, to realize their full nutritional value, grains with improved output traits cannot be marketed through "commodity" channels, but instead must be "identity preserved" both during production and marketing. To compensate growers for any added production and management cost (i.e., identity preservation of the crop; assays for specific traits) associated with producing grain or silage with improved nutritional traits, price premiums or production contracts between producers and users often are developed. For swine and poultry, grain hybrids richer in total oil, in specific amino or fatty acids, or in available phosphorus have immense potential. For ruminants, high oil grain hybrids can be very useful, hybrids with greater starch availability hold promise, and new hybrids with higher protein content or phosphorus availability may have potential. Although silage hybrids selected for leafiness and greater fiber digestibility often can increase milk yield by lactating cows, reduced forage yields currently limit their economic potential. Even though alterations in certain plant characteristics (e.g., higher grain yield, "stay green", slow kernel drying rate, waxy starch) may improve the nutritional value of corn silage, management factors (stage of silage harvest, grain processing during harvest, inoculation) probably exert even greater impacts on the nutritional value of silage. Dairy producers and cattle feeders who grow their own grain or silage are ideally situated to use hybrids with improved nutritional traits. Only when the economic value to the end user exceeds any increased cost of production will the trait-altered grain prove beneficial economically. However, economic value depends on local conditions. Increased production and management costs must be balanced 1) against reduced variability in nutrient composition of selected and identity preserved hybrids 2) reductions in diet cost due to increased concentrations or availability of nutrients,

and 3) effects on both animal production (feed efficiency, quality of animal products, animal health or longevity) and the environment (quantity and composition of excreta). Effects on yield and input costs should be obtained from local or regional test plots. Animal production benefits can be extrapolated from results of research trials.

Background

Since 1938, national corn grain yields have increased an average of 1.84 bushels per acre yearly due to selection of new hybrids; yields jumped further with introduction of the corn-borer resistance trait (Figure 1); genetic selection can explain about 60% of this increase. No other field crop has increased in productivity as dramatically and consistently. Rate of genetic progress depends on variation in the desired trait as well as number of traits included in the selection index. Whenever a new trait, such as enhanced nutrient content, is added to a genetic selection index, genetic progress is slowed. With some output traits, however, reduced insect damage or weed competition may increase yield or reduce risk. However, yield of hybrids selected for improved output traits typically lags behind yields of non-specialty hybrids. When a trait improves productivity and(or) reduces production cost, grain growers readily adopt grain with the new "input" trait and, being a direct benefactor, they willingly pay a premium price for seed corn that carries the trait. Although benefits of increased crop yields are readily apparent, hybrids with enhanced output traits may not benefit producers economically.

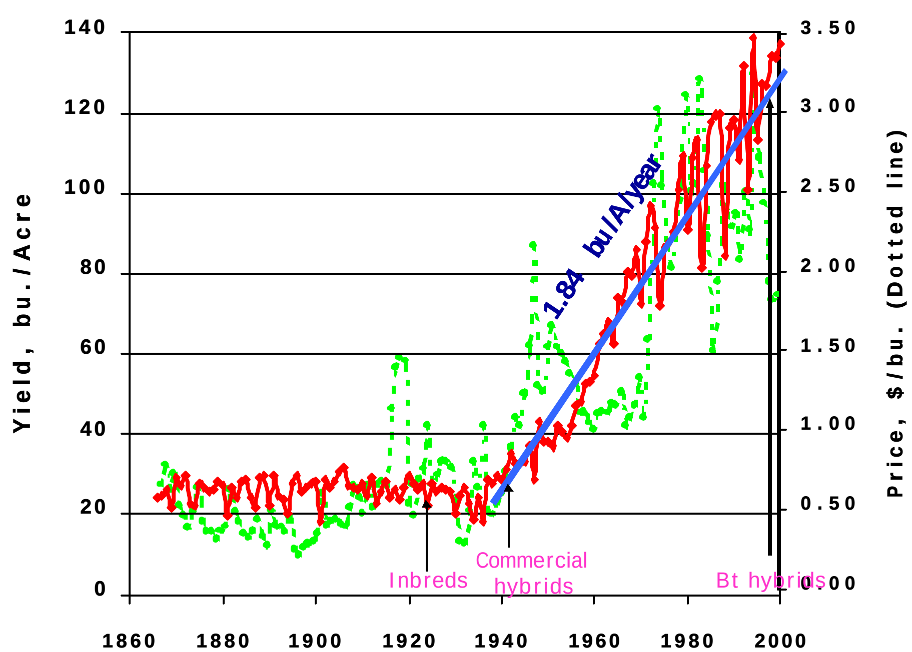

Figure 1. Corn grain yield (solid line), price (dotted line), and yield trend (straight line) from 1866 to 2000 (Values from the National Agriculture Statistics Service)

Many corn users in the past believed that "All corn hybrids are created equal, that they are endowed by their creator with certain inalienable nutritive characteristics." Yet, agronomic and nutritional traits of grain or silage can be readily modified by altering the genes of plants, either through traditional selection procedures (natural or induced genetic alterations) or by incorporation of specific genes from grain or other organisms (gene transfer or manipulation). Selection criteria will differ depending on interests of individuals at different points in the value chain. Grain producers who market their grain have been concerned about output (grain yield meeting minimum marketing specifications for their crop as commodity grain) as well as costs of seed, fertilizer, insect and weed control, and drying). As seed companies market directly to grain growers, interests of grain growers have been of primary concern to seed company geneticists in the past. Grain handlers and grain traders are concerned about transport cost and distance as well as stability of the grain during handling and storage. Livestock feeders usually have profit from feeding the grain or silage as their primary concern, and they may either purchase or grow the grain they use. Livestock feeders who purchase the grain they use should be concerned about nutrient and energy per dollar, absence of anti-nutritional factors (e.g., molds, and toxins), and quality of beef or milk per ton of grain purchased. In contrast, profit calculations for livestock producers who contract for grain or silage or raise their own grain or silage may prefer to calculate yield of animal products from each acre of land or dollar invested.

For decades, grain traders have used USDA Quality Grades initially developed in 1916 as the standard basis for trade. Unfortunately, nutrient content of grain within any USDA class can vary widely. With the advent of modified grain varieties and rapid analytical procedures, specialty grains should be marketed on the basis of nutrient content at some price premium or discount to the price of commodity grain. This paper is an attempt to outline altered agronomic and nutritional traits of current and experimental corn hybrids focusing primarily on traits that alter feeding value of grain or silage for ruminants.

Producing specialty grains

Growing grains with special output traits is not new. For decades, grain has been produced for specialty markets (food grade corn, white corn, waxy corn, hybrid seed corn, high amylose grain, modified silage hybrids). And recently, open-pollinated corn has re-emerged as a specialty grain selected because it is NOT genetically modified. Because specialty grains selected for improved output or nutritional traits usually provide little or no benefit to the grain grower, grain farmers that sell "commodity" grain on the open market have no incentive to grow grain with output traits desired by grain users. Consequently, grain growers must be rewarded with a price premium for producing grain with desired output traits. This premium serves both to compensate growers for potential reductions in yield of silage or grain as well as any added cost of preserving the purity and identity of their grain (often called "identity preservation" or IP) during production, handling, and marketing.

Specialty grains usually are marketed directly from producers to users through traceable channels and are not handled through traditional marketing channels as "commodity" grain. In contrast to "commodity" grain, IP grain usually is traded locally or through production contracts. Being both a producer and a user, a farmer-feeder can easily modify seed selection to produce crops with desired output traits and thereby can avoid the complexities of contracting. Identity preservation is being practiced by progressive grain elevators with many small bins rather than immense silos and by industrious grain traders. Certain multinational companies will contract with producers of specialty grains to meet the desires of domestic and foreign grain users. Thanks to rapid communication between producers and users via the Internet and dot-com companies, production of specialty grains is expected to expand rapidly.

Because they are identity preserved, specialty grains usually are more consistent, both physically and nutritionally, and often contain less foreign matter and fines than commodity grain; thereby, specialty grains often meets a higher USDA standard than commodity (#2 yellow dent) grain. In contrast, "commodity" grain often is blended and diluted with grain of lesser quality so that the final grain mixture meets minimum USDA quality standards. Such blending of higher quality grain with less costly, lower grade grain compensates for some of the cost involved with handling "commodity" grain. Consequently, the charge assessed for storage and handling often is greater for IP than for "commodity" grain. Yet, physical and nutritional consistency has value for grain processors (reducing dustiness and the need for frequent adjustment in processing equipment to produce a consistent product) and for livestock producers through improved animal health (reducing drastic changes in rates of digestion or ruminal fermentation that may result in acidosis and other metabolic diseases). Ability to trace IP grain back to its site of production also has value for processors in quality assurance programs for their consumers.

For test purposes, specialty grains typically are compared with one of two markedly different types of control grain – either the non-modified (isogenic) parent or the top yielding hybrid in an area. Comparison against the top yielding hybrid tests the yield potential of the trait-modified hybrid; this comparison provides economic data for grain growers about premiums to request. In contrast, the isogenic comparison tests the direct effect of the specific gene or trait on productivity or nutrient composition. The parental hybrid often is not the most highly productive hybrid available. Consequently, when compared to the parental or isogenic hybrid, one is testing the value of the trait, not the absolute productivity of the hybrid carrying that trait. Parental hybrids can differ widely in grain characteristics and in regional adaptability. As a result, grain possessing a given trait can differ due to base genetics and characteristics of the parent into which the trait has been incorporated. Unfortunately, grain with a specific desired trait may not be available in all grain production regions depending on availability of an acceptable parent. When yields are reduced by a trait or as compared with the top yielding hybrid in an area, grain growers must calculate whether compensation by the grain user fully compensates for the increased cost and risk associated with producing the specialty crop. Yield of specialty grains, relative to other hybrids, can be predicted most reliably from regional or local field tests of the grain hybrid available in a specific region. Producers of food grade and white corn have grown specialty hybrids for many years based on the increased value of output traits, so balancing value against production cost is not a novel concept. By adding new tools to the arsenal that plant breeders can use to improve hybrids, gene mapping, genetic engineering, and gene transfer will accelerate development of hybrids with new traits just as direct administration of growth hormone has increased milk production of highly selected and productive lactating cows.

Assay procedures

Historically, USDA grain grading standards (test weight, foreign matter, and heat damage standards) were used to assess grain "quality." These measures were designed to quantify the storage and handling characteristics of grain, not its nutritional value. Fair marketing of IP grain or silage with nutritionally altered traits requires assay for energy availability or for a specific nutrient or component of interest. For use in grain marketing, analytical procedures must be rapid, accurate, readily available, and economical. Although they remain the gold standard, direct chemical assays for nutrients usually are expensive and results are not immediate. For protein, oil, and moisture, marketed corn grain and soybeans are routinely analyzed today through scanning procedures using near infra-red reflectance (NIR) or near infra-red transmission (NIT) techniques. Similar scanning procedures for specific amino acids, oleic acid, and phytate are being developed. A single IR scan can quantify numerous nutrients simultaneously, but the cost of scanning instruments is quite high. Similar to futuristic plans to diagnose health problems by phone or the Internet, equipment that will scan an individual feedstuff locally and transmit that scan to a central location for interpretation may become available. An increased amount of information about nutrient composition of a livestock producer's diet ingredients from such scans also permits feed formulators to customize diets for specific animals (type, age, level of production) for an individual producer.

Opportunities and Challenges for Biotechnology

Benefits to the environment (reduced herbicide and pesticide use; reduced phosphorus excretion) and in health (reduced mycotoxin concentrations; increased concentrations of essential nutrients) can be obtained through the use of genetically altered grains. However, public concerns about the safety of genetic improvements and(or) protectionist governmental regulations among industrial countries currently restrict international trade of genetically altered grains. From an ethical and legal viewpoint, the public in both developed and developing countries should not be deprived of the potential for increased nutritive value and health and environmental benefits of specialty grains. Enhanced productivity under adverse production conditions (protection against regional insects or other plant pests; drought tolerance; salt tolerance) and animal and human health benefits from nutritionally enriched or mycotoxin resistant grains certainly are feasible through genetic modification. Due to reduced damage by insect pests, genetically modified grains certainly can reduce the cost of grain production and the use of pesticides. And with fewer acres required for producing grain for livestock or humans, less land needs to be devoted to crop production; this spares more land for "nature." As nutrient availability and balance of essential nutrients for animals and humans is improved, nutrient content of animal waste is decreased. This in turn reduces the environmental impact of livestock operations. While it is imperative that biotech companies exercise proper stewardship to protect the environment and human health, it is unfortunate that political decisions based "pseudo-science" and "fear of the unknown" often hinders the application of scientific techniques that could improve food safety and the quality of life.

Current governmental regulations that restrict international trade of grain and grain by-products are causing imbalances in the cost of grain and of food in certain geographic regions or nations. Restriction of imports or exports can cause regional or local shortages or excesses, particularly for byproducts or co-products of grain processing. Altered regional supplies, in turn, affects regional costs for feedstuffs and has forced some grain processors to transport byproducts very long distances to be nearer to byproduct users. Similarly, to meet the demand for grain that has not been genetically altered, specialty grain that has not been genetically improved is being produced and traded. The demand for rapid, sensitive analytical procedures for gene alteration can be expected to increase. It seems ironic that some of the new grain hybrids modified by American technology to prevent damage from an imported pest (the European Corn Borer) cannot be exported (deported) to the pest's site of origin!

Specific traits of current and experimental hybrids are listed below. Classification of whether a specific trait has been derived by transfer of a gene, either from a similar grain or from another crop or species, and thereby is classified as "Genetically Enhanced" or has been obtained by traditional genetic selection processes with or without induced mutations is noted. However, as new hybrids are developed and traits are being stacked within some hybrids, such classifications may change over time. Some of these traits may never be incorporated into commercial grain hybrids, and even if incorporated, hybrids with a given trait may not become universally available. Indeed, both the probability and timing of commercial release of specific traits is uncertain. In the race to market new traits, seed companies often release hybrids with sub-optimal agronomics and yield. Other factors that can limit development and delay release of hybrids with novel traits include: 1) difficulties in trait transfer and in trait stability in productive hybrids, 2) correlated traits that may adversely alter grain yield or its handling properties, and 3) inadequate economic return from bringing a trait to market, either due to limited value of the trait or to limited market potential. Although stacking several traits together can enhance usefulness and market share for a specific hybrid, stacking of traits usually prolongs the development process. Furthermore, new traits are incorporated first into specific grain parents that in turn are adapted to specific climatic conditions and insect pests; thereby, hybrids with a specific trait may not become available simultaneously in all regions of production.

Agronomic Traits

European Corn borer resistance

Genetically altered. Widely available in hybrids adapted to most regions, these hybrids contain specific insecticide proteins produced by the bacteria Bacillus thuringiensis (Bt) that are toxic to lepidoptera including the corn borer. For many years, farmers producing organic foods applied cultures of this bacterium directly to their crops to reduce insect damage. By transferring the specific genes responsible for producing the Bt insecticide into plants, and selecting plants that express one or more of these proteins, plants with Bt proteins have inherent resistance to the corn borer. Because Bt proteins are toxic for lepidoptera, butterfly larva that eat plant tissue containing Bt proteins are killed. Fortunately, larvae from other strains of lepidoptera normally do not consume corn plant tissues. In the years, regions, or fields where corn borers are prevalent, hybrids with various Bt proteins yield considerably more grain and silage than infected hybrids. With non-Bt hybrids, spraying for corn borers is recommended whenever one to six borers per plant are detected. But even after spraying, a 5% yield reduction can be expected with one borer per plant. Therefore, compared to non-Bt grain of similar genetics, yield is at least 5% greater for the Bt hybrid in the face of even a minor corn borer infestation. In a year or a region with a corn borer challenge, growing hybrids with the Bt gene will reduce both the cost of spraying and amount of pesticide used. In the absence of corn borer damage, productivity typically is no greater for Bt hybrids than for hybrids not containing one of the Bt genes. Nutrient content and value of both the grain and silage produced from a given Bt hybrid has been indistinguishable from that of the non-Bt parent (Faust and DeWitt, 1998, Faust, 1999; Folmer et al., 2000). Genes for several different Bt proteins have been transferred into corn plants. All coding for specific Bt proteins [CryIA(b), CryIA(c), Cry9a], various genes have been incorporated into hybrids and are classified as being the result of specific Bt incorporation “events” (176, BT11, CBH351, DBT418, MON810), but concentration of Bt proteins can differ with part of the plant. For example, in the 176 Bt hybrids, the Bt protein is expressed only in the stover (stalk, leaves, and husk) while most other Bt hybrids have Bt protein both in the stover and in the grain. To delay development of insect resistance to Bt, corn growers are expected to plant a “refuge” non-Bt hybrid near the Bt crop. This reduces Bt selection pressure against corn borers; eventually, strains of corn borers resistant to the Bt protein may develop. Corn hybrids with limited resistance to the corn borer also have been developed though selection, but, unfortunately, such plants typically contain more fiber and appear less digestible by ruminants. In one early study, feed to gain ratio was 5.5% poorer for growing calves fed corn silage from Bt than from typical corn hybrids (Hendrix et al., 2000). Beef cows also appeared to spend more time grazing stalk residue in fields from typical hybrids than from Bt hybrids (Hendrix et al., 2000); greater grazing time may reflect more corn borer damage and more dropped ears in fields following harvest of the non-Bt hybrid. In contrast, two years of cattle trials from Iowa State University (Russell, 2000) have detected no difference in preference or in performance of cattle fed corn stalks from Bt vs non-Bt parental hybrids. They found that stalk moisture was retained longer by Bt than non-Bt hybrids; this may delay mechanical harvesting of stalks. Russell (2000) noted that field loss of ears and grain was lower for Bt hybrids in the year with greater corn borer pressure. This reduction in field losses will reduce the supply of grain available both for cattle grazing stalk fields and for wildlife (deer, pheasants) that thrive on residual grain.

Corn rootworm, Southwestern corn borer, Armyworm, Corn earworm, Common stalk borer resistance

Though Bt hybrids will partially reduce damage from these pests, control is incomplete. Corn rootworm control with plants genetically engineered to express Bt endotoxin are being field tested by Monsanto according to a recent article in the Washington Post, so release of such hybrids probably is imminent.

Herbicide resistance

Genetic alteration. Widely available in hybrids adapted to most regions. Through incorporating genes encoding for enzymes that degrade specific herbicides, hybrids have been developed that are resistant to specific herbicides (glyphosate or Roundup™; imadazolinone or Contour™, Resolve™, and Lightning™; glufsinate ammonium or Liberty™). This resistance allows producers to apply specific herbicides to control diverse types of weeds without harming the growing corn plant. Presence of the Roundup™ resistance trait in both corn silage and corn grain did not alter production of milk, milk composition, and production efficiency by dairy cows (Donkin et al., 2000). One theoretical concern raised by environmentalists is that genes that provide herbicide resistance might be transferred to other species of plants; this could reduce the effectiveness of a herbicide and lead to development of "superweeds." Also, grain producers who rotate crops and use herbicides to control volunteer plants prefer herbicide sensitive hybrids. One feedlot manager complained that his normal broad-spectrum herbicide no longer controlled volunteer corn plants near his feed mill or feedbunks, apparently because the grain he had purchased to feed was tolerant to that herbicide!

Storage Traits

Fumonisin resistance

Genetic alteration. Soon available in certain hybrids for certain regions. Although less toxic than aflatoxin, fumonisin reduces feed intake and productivity of nonruminants and can prove toxic for horses. Hybrids that produce grain resistant to fusarium have been developed while hybrids resistant to other field and storage mycotoxins are being studied. Presence of stress cracks increases fungal access to grain, so grain damage during harvest and drying increases susceptibility of grain to development of mycotoxins during storage. Hybrids with thicker pericarp (seed coat) and more vitreous endosperm also resist fungal attachment, so selection for an altered pericarp or less soft starch should decrease mycotoxin levels. Unfortunately, such structural alterations of the grain may reduce starch digestibility by ruminants and increase the need for extensive grain processing. Selection against fungal attack also may reduce presence of certain fungal products that have proven useful for livestock producers. Zeranol, the estrogenic ingredient in the growth-stimulating ear implant Ralgro, is produced by a mold that grows on corn grain. Smut, another fungal product, is a valuable corn-byproduct in Mexico and Central America where fried smut is considered a tasty food delicacy; incidence of smut also seems to have increased among U.S. politicians in recent years! Because of reduced plant stress and insect damage of corn kernels, concentrations of several mycotoxins, particularly fumonisin, have been reported to be lower for hybrids possessing the Bt trait (Munkvold and Hellmich, 1999). Reduced mycotoxin concentrations certainly will decrease the incidence of fungi-related disorders and diseases of both animals and humans, thereby improving the safety of our food supply for both animals and humans.

Nutrient composition

Oil concentration

Non-genetic alteration. Available in several hybrids, primarily grown in the central Corn-Belt. Typical corn grain contains about 4% oil, primarily in the embryo. Through selection, hybrids with very high oil content (19% oil) but very low grain yield have been developed; higher yielding hybrids with enhanced oil (5-6%) also are available. Through the Top Cross™ system, female plants of specific hybrids, selected because their tassels do not produce viable pollen, receive pollen from high oil pollinator plants (about 8% of the plants in the field) and yield grain with elevated oil content (over 7% oil). With Top Cross™ hybrids, stover composition is not altered, but the grain, due to a much larger embryo, carries more oil (Table 1). As the embryo partially displaces the endosperm, starch content of the grain is reduced proportionally. But because oil has 2 to 3 times more net energy than starch, energy content (both gross and net) is greater for high oil than typical grain. Because the limited number of pollinator plants present in the field produce kernels that are very rich in oil but are small

Table 1. Reported nutrient composition [a] of dry matter of grain selected for specific nutritive traits from hybrids marketed through various seed companies but licensed by either DuPont Specialty Grains (High Oil Corn), ExSeed Genetics L.L.C. (Nutridense), or Dow AgroSciences L.L.C. (Supercede).

Item	Typical	High oil	Change %	Typical	NutriDense	Change %	Typical	Supercede	Change %
Protein	9.23	9.83	6.4	8.9	11.4	28.2	9.1	10.3	13.2
Oil	4.03	7.36	82.4	3.4	5.3	56.7	4.0	6.4	60.0
Crude fiber	2.27	2.40	5.6	2.3	2.3	0.0	2.2	2.2	2.3
Starch	71.40	67.91	-4.9						
NDF	7.06	7.59	7.6	8.0	8.0	0.0			
ADF	2.99	2.87	-3.9	3.3	3.3	0.0			
Ca	0.01	0.01	0.0						
P	0.28	0.30	8.3	0.3	0.4	23.1	0.3	0.3	17.9
Ash	1.33	1.45	9.6						
ME (swine)	1777	1858	4.6	1761	1815	3.0			
NEg[b]	70.8	76.0	7.3	68.2	70.5	3.3			
NEl[b]	95.1	100.5	5.7	93.2	96.6	3.7			
Lysine	0.29	0.34	16.0	0.3	0.4	29.2	0.3	0.3	13.8
Methionine	0.21	0.23	11.1	0.2	0.2	31.3	0.2	0.2	4.8

[a] Analyses obtained from www.dupontsg.com/pork/ProductInformation/OHOCOverview.htm, www.exseed.com/nutri.html, and www.dowagro.com/supercede.html.
[b] Calculated from nutrient composition using equations of Weiss (1997).

and hard, high oil corn must be processed to permit all of its additional energy to be digested. Feeding trial results with high oil corn are summarized in Table 2. Based on these data, rate and efficiency of gain were increased by 3 to 4% by substituting high oil corn for typical corn grain when the grains were processed. But when fed whole, high oil corn often has failed to improve rate or efficiency of gain, supporting the concern that high oil grain must be processed to obtain full value from its additional gross energy. As with traditional hybrids, specific high oil corn hybrids differ chemically and physically; thus, feeding value for ruminants depends on parentage or base genetics. In the case of top-cross hybrids, specific seed traits (e.g., starch form, structure, or density that can alter digestibility) can be transferred to the grain from the high-oil pollinator, in addition to the high oil trait. Feed intake by lactating cows typically is greater with silage from high oil hybrids and persistency of milk production often is increased (Harbaugh, 2000; Linn et al., 2001). This is similar to effects noted from addition of other sources of fat or oil to lower-fat diets for lactating cows. Several meat quality advantages have been detected with steers fed high oil corn. First,

Table 2. Impact of high oil corn on gain, intake, and feed efficiency of feedlot cattle based on feeding trial experiments. Weight gains were adjusted for differences in dressing percentage.

	Grain form			
	Flaked	Rolled	Whole	Ensiled
Trials	2	4	4	2
Cattle, number	200	180	281	220
ADG response, %	3.8	2.75	-3.57	2.72
DMI response, %	-0.55	-0.76	-2.25	-0.67
Gain/Feed response, %	4.32	3.54	-1.34	3.28

presumably due to higher tocopherol content of both grain and meat tissues, beef shelf life of steaks was extended for as much as 2 days by feeding steers high oil corn (Johnson et al., 2000). Case life of ground beef was 2 to 8 days longer when the steak trimmings were obtained from steers fed high oil corn plus vitamin E than when fed typical corn with or without vitamin E (Eibs et al., 2001). Second, tenderness and juiciness both were greater for ribeye steaks from steers fed high oil corn than from steers fed typical corn (Duckett et al., 2000).

Fatty acid composition

In some cases, genetically altered; in other cases, not genetically altered. Altered safflower and sunflower seed are available commercially; genetically altered corn and soybeans are being developed but are not commercially available as yet. Chemical composition of the fatty acids in oil present in corn, soybeans, safflower, and sunflower can be altered readily. Deposited directly in tissues of non-ruminants, dietary fat or oil with a higher melting point can increase the melting point of depot or milk fat so that tissues or animal products are more liquid at room or at refrigerator temperatures. This can alter carcass-handling properties, such as the ease of slicing bacon. Effects are less drastic with ruminants because 60 to 80% of the unsaturated fatty acids are saturated during transit through the rumen. Consequently, oil composition of the diet has less impact on composition of tissues from ruminants than from nonruminants. Nevertheless, concentrations of nutritionally desired unsaturated fatty acids of ruminant tissues and milk often are elevated slightly when dietary fats are less saturated. This, in turn, can influence handling properties of ruminant products. Of special interest with ruminants is the production of conjugated linoleic acids (CLA), anti-cancer chemicals that are produced by fiber-digesting bacteria found in the rumen and deposited in ruminant milk and meat. Derived from linoleic acid in feeds, CLA content of meat and milk and milk products can be increased through increasing the linoleic acid content of the diet. Although human nutritionists suggest that higher intakes of linoleic and linolenic (particularly omega-3 fatty acids) can help decrease the incidence of cardiovascular disease in humans, meat and other food products that contain abnormally high concentrations of long chained unsaturated fatty acids (linoleic and linoleic acid) have increased rates of oxidative rancidity. This makes oleic acid enriched meat and milk, produced from ruminants fed high oleic acid hybrids, preferable to linoleic-enriched animal products for food processors. Meat and milk with grassy flavor typically has a higher linolenic acid content, and “fishy” odors can be transferred from fish oils to meat and milk. Grains and oilseeds with customized fatty acid composition have been found to improve quality and stability of meat and milk products (e.g., butter).

Protein content

Developed by selection, but also highly dependent on N fertility of the soil. Commercially available in some areas. Hybrids richer in protein (11%) and moderately high in oil (5%) have been developed (Table 1). These nutrients again displace starch content of grain. Although the added protein can replace other sources of protein in the diets of ruminants, protein from corn grain, being about 50% zeins, is notoriously low in two essential amino acids - lysine and tryptophan. Consequently, bypassed corn protein has questionable nutritional value for ruminants. Higher rates of N fertilization usually increase both grain yield and protein content of the grain, but simply increasing protein content of grain can be either desirable or undesirable depending on which protein types are altered. Protein in the embryo portion of the corn kernel has a desirable balance of amino acids whereas prolamins, the proteins that embed starch granules in the endosperm portion of the kernel, have low biological value. Furthermore, through embedding starch granules in a protein matrix, prolamins reduce accessibility of vitreous starch to either bacterial or enzymatic digestion. Consequently, grain with higher concentrations of specific prolamins usually has a lower starch digestibility. This indicates that simply increasing the protein content of grain by manipulating genetics or fertilization may not enhance the nutritional value of grain for livestock feeding. In contrast, targeting for a decreased concentration of specific prolamins in the grain may increase starch availability and reduce the need for extensive processing (e.g., steam flaking) of corn grain.

Amino acid concentrations

Selected naturally or altered genetically. Amino acid concentrations differ slightly among current hybrids (Table 1), but varieties with markedly increased concentrations of specific essential amino acids have not yet been commercialized except for the opaque-2 hybrids developed several decades ago. Through gene transfer, hybrids enriched in total protein as well as in free lysine and methionine have been produced. These specific amino acids can displace other sources of supplemental amino acids added to diets for nonruminants. In some cases, the additional amino acids in modified grains are components of protein; in other cases, the additional amino acids present are not components of protein but are “free.” Ruminal escape of free amino acids is limited, so hybrids enriched in protein-bound rather than in free amino acids should be preferable for feeding ruminants. Responses to an improved amino acid balance of rumen escape protein should be expected only with ruminants that need high amounts of essential amino acid (lactating cows; rapidly growing calves). In contrast, some ruminant nutritionists have suggested that plant breeders should select for corn grain hybrids with lower protein content so that more supplemental protein of higher quality could be replace protein from corn in the diet and thereby N intake and N excretion could be reduced. Simply avoiding excess supplementation should be a simpler approach to the problem of excess N excretion. Because supplemental amino acids are marketed commercially and are relatively inexpensive in developed countries, amino acid enriched hybrids will have limited marginal value. The value of amino acid enriched hybrids for livestock would be greatest when stacked with other traits, when used in regions of the world where amino acid supplements are not available or in diets not feasibly supplemented (as with human diets), and when environmental concerns require producers to reduce N excretion by avoiding excesses of amino acids. When one considers diets for swine, increasing the lysine concentration in a cereal grain will decrease the amount of supplemental protein (e.g., soybean meal) that needs to be added to the diet to meet the pig's lysine requirement. However, if the lysine:protein ratio is not increased, dietary concentration of N and N excretion will not be reduced. So from an environmental standpoint, effects of altering the lysine content on total protein content of the diet, not simply the ratio of corn to soybean meal, needs to be considered.

Starch content and type

Current hybrids differ in starch content due to dilution (as influenced by environmental and genetic factors) and in starch type due to genetic alterations obtained by traditional selection procedures. The primary energy reserve in cereal grains, starch can be classified by chemical type – amylose and amylopectin, and by packing density within the corn kernel – floury (soft) and vitreous (hard). Proportion of each starch type will vary genetically whereas vitreousness varies with genetic and environmental conditions and kernel maturity. Waxy grain contains no amylose, typical yellow dent grain contains 20 to 30% amylose, and high amylose grains usually contain 50% to over 80% amylose. Having more exposed ends for attack and being less densely packed (that speeds water uptake), amylopectin is more rapidly and completely degraded by bacteria and digestive enzymes than amylose. High amylose corn grain is slowly fermented in the rumen even after such grain is flaked. When not extensively processed, waxy grain generally has improved both the rate and efficiency of gain by steers as compared with corn grain containing more amylose (Table 3) based on studies from Henderson (1974) and Johnston and Anderson (1992, 1993). However, more extensive grain processing (flaking)

Table 3. Summary of results from seven steer feeding trials where rolled or ground typical or waxy grain was fed with diets containing 70% or more grain.

Starch type	ADG, lb.	DMI, lb.	Feed:gain
Typical grain	3.19 [b]	19.72 [b]	6.17
Waxy grain	3.36 [a]	19.98 [a]	5.92

[a,b] Means in a column with different superscripts differ ($P < .05$).

removed this advantage for waxy grain (Henderson, 1974). Total tract starch digestibility from corn grain by ruminants varies drastically with processing, averaging about 85% for whole grain, 94% for dry rolled or ground grain, 96% for high moisture (fermented) corn grain, and over 99% for flaked corn. This indicates that energy value of grain is much greater for extensively processed grain. But even after corn was flaked, differences in rate and extent of digestion among elite hybrids have been detected indicating that all hybrids are not alike. More densely packed than soft starch, vitreous starch comprises a larger portion of grain classified as "flinty." As compared with "dent" grain, whose pericarp indents because the soft starch shrinks and the seed coat collapses as the grain matures and dries, flint corn is more rigid externally. Thereby, grain that is more "flinty" resists fracture during handling and is less rapidly (and less extensively) fermented in the rumen (Correa et al., 2001). Shorter-day hybrids and newly released hybrids available in many regions of the U.S. tend to be more "flinty" than longer day hybrids and traditional hybrids. The more flinty the grain, when not processed prior to feeding, the slower the fermentation in the rumen and the greater the benefit from extensive grain processing. Though ruminal escape of starch may be greater for flint corn than dent corn hybrids (Philippeau et al., 1999), postruminal digestion of vitreous starch, when not processed, may be limited. Total starch content of grain depends on dilution by other components, e.g., embryo and pericarp. Because the fibrous pericarp comprises a larger portion of small than large kernels, smaller kernels often have a lower percentage of starch. Though a larger embryo may not decrease net energy value of grain for livestock, displacement of starch by a thick, fibrous pericarp definitely decreases the net energy value of the grain.

Variability in nutrient content

Identity preservation of specialty grains involves additional cost and effort, but identity preservation also can reduce product variability. Variability within a grain hybrid typically is less than variability among hybrids. Consequently, if one or a few select hybrids similar in composition are grown, variability in nutrient content and physical properties of the grain produced will be reduced. In Table 4, means and variation in nutrient content of corn grain are compared. Values were derived from tables compiled as a national average (NRC, 1996), the minimum specifications for #2 yellow corn grain, an average across 127 Pioneer hybrids, and grain contracted and delivered to two Kansas feedyards in 2001. One of these feedlots accepted grain from all local grain growers while the other specified that corn suppliers should grow and deliver one of four specific corn hybrids. Compared to the feedlot that accepted grain of unspecified hybrids, the feedlot that specified which hybrids would be accepted from corn growers received grain with higher concentrations of protein, oil, and starch and less variability in each of these measurements. Whether these benefits were due fully to avoiding hybrids with abnormally low nutrient content or abnormal kernel characteristics or should be ascribed partly due to improved management and quality control by the grain suppliers is not known. Certainly, the percentage of samples with abnormally low CP and oil content was markedly reduced when acceptable hybrids were specified. Through using grain of specified origin, variability in grain hardness and in processing cost and consistency also can be reduced markedly.

Table 4. Means and variability of measures of corn grain of unspecified or specified origin.

Item	NRC (1996)	All hybrids (1998)	Unspecified hybrids	Specified hybrids
Sample number	134-3579	127	>500	1328
Analyses				
Protein, % of DM	9.80 ± 1.1	8.89 ± 0.63	8.94 ± 0.67	9.12 ± 0.49
Oil, % of DM	4.1 ± 0.6	4.0 ± 0.30	3.7 ± 0.49	4.3 ± 0.24
Starch, % of DM	-	70.3 ± 1.0	71.6 ± 1.1	72.9 ± 0.6
Measures	#2; USDA (1995)			
Weight, lb/bu.	> 54.0	-	-	59.7 ± 1.4
Foreign matter, %	< 3.0	-	-	1.2 ± .9

Nutrient Availability

Starch availability

Varies among commercial hybrids. No tables are yet available for specific commercial hybrids. Ease of starch extraction during wet milling of grain differs among hybrids; extractability ranges from 77% to 96% of total starch among diverse hybrids. Grain with starch that is more easily or extensively extracted is preferred by grain processing industries that remove the starch for manufacturing fructose or ethanol, but whether hybrids with more easily extracted starch have greater value for feeding livestock has not yet been determined. Though the ratio of gross energy to metabolizable energy values for feeding pigs differs among corn grain hybrids (Fent et al., 2000), total tract digestibility of starch by swine generally exceeds 99%. Nevertheless, starch that is fermented in the large intestine rather than digested in the small intestine should have lower energy value than starch digested in the small intestine. Except for flaked grain, starch digestibility is considerably lower for ruminants than for nonruminants. Net energy values of grain for cattle appear to be reliably predicted from concentration of starch in feces; presence of starch from the roughage source (corn silage) and dilution of feces by higher fiber levels must be considered when interpreting this measurement. To aid both plant breeders and grain users, analytical procedures that rapidly and reliably predict site and extent of starch digestibility are needed.

Phosphorus availability

Several genetic strains that differ in various steps in synthesis of phytate have been developed through selection; additional strains have been developed through gene transfer. Several low phytate hybrids suitable for growing in the southern corn belt have been released commercially. Most of the phosphorus in typical cereal grains is bound to inositol to form phytate. Because nonruminant animals lack phytase, the enzyme that cleaves phosphorus from inositol, dietary phytate phosphorus is largely excreted in feces by nonruminants. Ensiling of grain or addition of phytase from yeast or other microbes to diets for poultry and swine will increase phosphorus availability and, through reducing the amount of phosphorus that is added to the diet, can decrease excretion of phosphorus, an environmental pollutant associated with stream eutrophication. Strains of corn that produce grain with less phytate, known as "high available phosphorus grain," also have been developed. Typically, phytate-bound phosphorus comprises about 20% of total phosphorus in high available phosphorus grain (0.075-0.11% phytate in the grain) compared to over 80% (0.23-0.30% phytate) in typical grain. Bacteria in the rumen also produce phytase, but the degree to which bacteria degrade feed phytate during the passage of feed through the rumen is uncertain. Traditionally, phytate was considered to be completely degraded in the rumen, but research in a thesis from Louisiana (Sansiñena, 1999) indicated that 28 to 47% of dietary phytate (largely from rice bran in that study) escaped cleavage in the rumen. Even if low phytate corn grain has greater phosphorus availability for ruminants, effects on phosphorus pollution by ruminants are unlikely because many ruminant diets, particularly those that include corn byproducts like corn gluten feeds or distillers products, are not supplemented with phosphorus. Diets for very rapidly growing ruminants or for lactating cows not fed grain byproducts usually contain added phosphorus; the need for supplemental phosphorus might be reduced if phosphorus availability from grain were increased. However, performance trials conducted to date have shown no advantage for high available phosphorus hybrids in either rate or efficiency of growth. Surprisingly, such hybrids may have other beneficial effects on carcass quality and meat composition; these items currently are being studied.

Additional traits

Through gene transfer or through selection, hybrids enriched with specific antioxidants, antimicrobial compounds, plant or animal growth modifiers, flavoring compounds, biodegradable "carbon neutral" plastic substitutes, drugs, and metabolic modifiers are being developed. Plants, like microbes, are becoming factories for production of numerous specialty proteins and lipids (ethanol; biodiesel; biodegradable plastics). Production of such compounds should increase the supply of plant and grain residues (byproducts or co-products); because of their high fiber content, such products are likely to be fed to ruminants. Because most industrial extraction processes yield byproducts that are wet and expensive to dry, preserve, and transport, such byproducts are likely to be fed near the site of production. Through serving to both de-water wet residues and digest fiber, ruminants assist humans in waste management and ruminants of the future should be considered friends, not polluters, of the environment.

Silage Traits

Leafy silage hybrids

Developed through selection. Specific hybrids are currently available for many regions. Silage digestibility and nutritive value for ruminants can be enhanced either by 1) increasing digestibility of fiber (NDF) or 2) increasing the proportion of constituents (grain) that are more digestible than NDF. Having extra leaves above the ear, leafy hybrids often have greater forage digestibility because the leaf to stem ratio is increased. Selection for greater fiber digestibility must be based on research with stover. Unfortunately, stover composition varies dramatically with environmental conditions and maturity. Nevertheless, feed intake was 4% greater and fat-corrected milk production was 3.5% greater for lactating cows fed a leafy corn silage hybrid (Clark et al., 2000), so production (but not efficiency) may be increased through selection for silage for plant leafiness. Although direct selection for silage traits (greater fiber digestibility; slower grain drying) certainly seems desirable, selection for grain yield should be a more reliable and repeatable method to increase silage digestibility than selection for stover digestibility. This is because numerous uncontrolled factors (maturity, moisture content, time of day harvested) can influence silage value. Fortunately, selection for greater grain yield usually increases total silage yield (tons of dry matter per acre) and(or) digestibility (through increasing the grain to stover ratio) if the grain is adequately digested. However, exceptions can occur. For example, wheat selected for higher yield and reduced field loss has led to development of short, stiff stems (with more lignin); such selection has reduced both straw yield and straw digestibility. Similarly, selection for hybrids for reduced field loss of loss of ears (e.g., less corn stalk snap) may increase the concentration of indigestible fiber in stover. Certainly, selection of corn hybrids with shorter stature can decrease stover yield. In a study from South Dakota (Mueller et al., 2000), a forage type corn silage (19 vs 30% starch) produced 6% slower ($P < .10$) and less ($P < .02$) efficient gains by growing steers fed diets containing 88% corn silage. But because dry matter yield was 19% greater for the forage hybrid, beef production per acre was 14% greater for silage produced from the forage than from the higher grain, presumably short stature hybrid. For selection of ideal silage hybrids, both relative yields of net energy and the optimum energy density of the diet to achieve a desired level of animal production must be considered.

Brown midrib (BMR) silage hybrids

At least four different mutants (bm1, bm2 bm3, bm4) have been identified in corn grain (Lauer and Coors, 1997) and both BMR corn and BMR sorghum hybrids suited for many climates are available commercially. Containing less indigestible fiber, particularly lignin, corn silage hybrids with the brown midrib trait have more digestible stover than typical hybrids. ADF and NDF typically are 3 and 2% lower for BMR hybrids (Lauer and Coors, 1997). Consequently, lactating cows or growing beef steers typically eat more of silage-rich diets when fed brown midrib hybrids (Tjardes et al., 2000; Qiu et al., 2000). This increased feed intake, in turn, may explain the increased milk production often observed with BMR silage (Qiu et al., 2000). Such performance benefits from BMR were not apparent for growing cattle fed silage (Tjardes et al., 1999) or finishing cattle fed diets containing low amounts of fiber. Two items about brown midrib hybrids are of concern. First, because of the brown leaf color, producers often harvest brown midrib silage at a less mature stage; early harvest can result in seepage losses from the silo as well as undesirable fermentation and silage handling characteristics. Second, with less rigid stalk support, silage dry matter yield can be 20% lower for BMR hybrids (Ruppel and Mahanna, 1997). Extent of field loss of grain and stover associated with downed stalks certainly can vary with hybrid, harvest date, and weather stress. Harvesting typical hybrids at a greater height (leaving the lower portion of the fibrous stalk in the field) should have similar effects on concentration of indigestible fiber in silage as switching to BMR hybrids providing the diet is formulated to take advantage of the higher net energy of the silage. Nevertheless, selection for a lower fiber and lignin concentration in the stalk and in the grain should increase availability of both energy and nutrients and may increase intake of high roughage diets.

Waxy silage hybrids

The waxy gene, a recessive trait, has been isolated and transferred through genetic selection. Waxy normal and waxy high oil silage hybrids are available commercially in some regions. Waxy grain silage hybrids generally have higher starch digestibility than typical silage hybrids due to higher amylopectin content of starch as discussed above. As digestibility of starch from corn grain generally declines as the grain matures, dries, and hardens, the digestibility advantage for waxy grain increases when silage harvest is delayed. Similarly, grain processors that mechanically crush the kernels and thereby increase starch digestibility, particularly if grain is more mature (ZoBell et al., 2000), should reduce the advantage of waxy silage hybrids. Mechanical processing, through decreasing particle size of the fiber that in turn reduces its ruminal retention time, may decrease digestibility of fiber. Increasing chop length of processed corn silage may compensate for this effect and help to maintain higher ruminal pH and fiber digestibility of processed corn silage (Onetti et al., 2001). Fat-corrected milk production was 6.4% greater for cows fed waxy (grain plus silage) than for cows fed silage from either typical or Nutridense corn types. This was ascribed to 2% greater feed intake (Akay and Jackson, 2000a) as well as greater total tract starch digestibility (89 vs. 83%) with waxy corn diets (Akay and Jackson, 2000b).

High oil silage hybrids

Hybrids have been developed through selection of grain for high oil content for decades. Because oil content of stover is not altered in typical Top Cross™ high oil hybrids, oil content of silage is increased less than oil content of the grain. In several trials, feed intake and milk production have been increased when high oil (silage plus grain) replaced typical hybrids (Atwell et al., 1988;

LaCount et al., 1995; Drackley, 1997; Harbaugh, 2000), particularly in full lactation trials where persistency of milk production has been enhanced (Weiss and Wyatt, 2000; Linn et al., 2001). Although milk production has not always increased when high oil corn silage has been substituted for typical corn silage (Whitlock et al., 2000), an increased ruminal supply of polyunsaturated fatty acids from high oil corn has consistently increased CLA concentration of milk (Whitlock et al., 2000).

Economics of Producing and Using Specialty Grains

To compensate for the increased cost involved with research, development, and production of specialty hybrids, specialty seed grains sell for a higher price than typical seed. Additional cost may be involved with identity preservation, nutrient analyses, yield reductions, and increased risk of producing a specialty hybrid. Yield estimates should be based on comparison of hybrids at nearby test plot locations. Livestock producers growing their own grain or silage or those purchasing grain or silage need to include several factors when calculating the added value of specialty grains. These include:1) the change in cost of the ration and its handling (e.g., replacement of purchased fat by oil from high oil corn that can be calculated by feed formulation specialists), 2) the economic benefit from the expected response in rate or efficiency of production and persistency, 3) any economic benefit obtained from an altered value of livestock products (carcass quality advantages; milk fat percentage), 4) the intrinsic value of a diet alteration (e.g., avoiding fat and protein from animal sources in ruminant diets by using high oil corn), and 5) improvements in diet consistency (reduced batch-to-batch variation in nutrient content, processing speed, ease, and consistency, and fermentation rate that can lead to acidosis). Although some individual farms have the capacity to compare yields of various grain or silage hybrids, on-farm animal production comparisons are extremely difficult to interpret because numerous variables (changes in weather or in other diet ingredients over time; differences in animal background or in stage of lactation) are difficult to control. Consequently, animal productivity or product value changes with specialty hybrids are quite difficult to quantify. Instead, comparisons should be derived from data compiled from research trials. Experiment station personnel as well as seed company representatives or scientists usually have the software, training, and data to help producers make the critical economic decisions for individual producers about growing or using grain with modified agronomic or nutritional traits.

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