Nutritional Benefits of Specialty Corn Grain Hybrids in Dairy Diets[1]

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ABSTRACT

Corn grain is a primary energy supplement in dairy diets and can contribute up to 30, 60, and 98% of the diet's protein, net energy, and starch, respectively. Specialty corn hybrids are one result of efforts to select corn based on nutrient content. Many of these hybrids, which include high lysine, high oil, waxy, white, and sugary, among others, have been the subject of renewed interest because of improvements in agronomic performance, commitments by marketers to preserve the identity of specialty grain, and improvements in our understanding of digestion and nutrient requirements. Nutrients targeted in corn for dairy cattle include protein content, amino acid quality (especially lysine and methionine that escape ruminal fermentation), starch (including form, texture, and digestibility), lipid content, fatty acid composition, and mineral composition and availability. Concentrations of protein and oil are highest in the germ, and both are negatively correlated with starch concentration. Efforts to improve lysine content are hampered by its negative correlation with total protein. Lactation studies to date have shown variable production responses to specialty corns; their value may be limited to replacing more expensive ingredients in dairy diets. Increasing the protein content of corn would have the most economic value in diets for cows producing less than 9500 kg per lactation. High lysine corn is currently of limited value; increases in ruminally undegraded lysine would increase its value in diets for cows producing more than 9500 kg per lactation. At current fat ingredient prices, high oil corn has limited economic value except in diets for very high production.

(**Key words**: corn, lysine, oil, economics)

Abbreviation key: **NFC** = nonfiber carbohydrate, **QPM** = quality protein maize.

INTRODUCTION

Traditional criteria for selecting corn hybrids have been based primarily on agronomic factors, including grain production, disease resistance, drought tolerance, and storage characteristics. Little emphasis has been placed on the nutritional value of corn for livestock. Grain producers have been reluctant to select hybrids based on nutritional quality because few incentives have been in place that add economic value to corn with improved quality. Even though livestock producers could take advantage of higher quality grains they produce themselves, they have not presented consistent or unified requests through their purchases from grain or seed suppliers to strongly influence corn breeding programs.

Fortunately, the lack of financial incentives for nutritional quality is diminishing (23). With major efforts by grain handlers to preserve the identity of specific grains, financial rewards are being provided for nutritional quality, and seed companies and corn producers are responding by increasing selection and production of these grains (19). Consequently, dairy producers will soon have available to them numerous hybrid choices that excel in certain nutritional characteristics. These choices will likely originate from both high grain-yielding germplasms currently available in commercial hybrids and from single-gene mutant germplasm, or specialty corns, that continue to narrow the grain yield gap between themselves and traditional high grain-yielding hybrids. The challenge to dairy producers and nutritionists is to identify which hybrids add the most value to their feeding program and increase profitability.

The objectives of this paper are to review the nutritional value of different corn hybrids for lactating dairy cows, with a focus on the recent advances of specialty hybrids. A broad look at the economic value of these hybrids in various dairy diets will be taken to determine the relative position each hybrid may have in different feeding situations.

[1]The author thanks Southern Illinois University (Carbondale) and Crow's Hybrid Corn Company (Milford, IL) for support.

DISCUSSION

Selection for Nutritional Quality

As with all ingredients used in dairy formulation, the inclusion of corn grain is based on its nutrient contribution relative to its cost. As an ingredient in dairy diets, corn is used primarily as an economic source of fermentable carbohydrate, but it is limited in value because of deficiencies in several nutrients. According to the NRC (33), a lactating dairy cow producing 48 kg of milk/d requires a diet containing 1.72 Mcal of NE_L/kg, 17% CP, 5.9% RUP, 25% NDF, 3% lipid, 0.64% Ca, and 0.41% P. Compared with these specifications, normal corn is deficient in CP, RUP, NDF, Ca, and P and contains excess NE_L (32) in the form of excess nonfiber carbohydrate (**NFC**). Other nutrients that may be important in corn include essential AA such as lysine and tryptophan, especially if they bypass ruminal fermentation, lipid and lipid composition, and other essential minerals and vitamins. Ruminal and total tract digestibility of each of these nutrients is also variable and deserves consideration. As improvements in our understanding of nutrient requirements and diet formulation continue, additional nutrients are likely to become important selection criteria for corn grain. Not all nutrients can be selected simultaneously for maximum progress in nutrient quality. The relative emphasis on each trait should be based on the genetic variation, heritability, and economic value of each, which is the basis for index selection (6, 42).

Selection for nutritional quality of grain may be possible within currently available hybrids. Table 1 illustrates the variation in nutrient composition for nearly 300 genotypes for hybrids from Pioneer Hi-Bred International, Inc. (Johnston, IA) (B. Mahanna, 1997, unpublished data). These samples ranged in protein content by almost 4% units, in starch by 6% units, and in lipid by almost 2% units. Progress in nutrient selection, however, may be challenged by the presence of negative correlations among important nutrients. Protein content ($r = -0.52$) and oil content ($r = -0.44$) were inversely related to starch. Therefore, selection for these nutrients would decrease the fermentable energy of corn. Lysine content as a percentage of protein decreased 0.3% units for each percentage point increase in protein content, probably because of higher proportions of lysine-poor zein protein (10). Kornegay et al. (25), however, reported no relationship between lysine and protein content of corn. Perhaps most challenging is the negative relationship between time and protein content with an observed 0.4% unit decrease in protein content per decade since 1930, apparently because of increases in grain yield (B. Mahanna, 1997, unpublished data). Whether nutrient value should be sacrificed for the sake of additional grain yield again requires critical evaluation of weights to be used in multiple trait selection indexes.

TABLE 1. Nutrient variation within regular corn hybrids.[1]

	DM (%)		
Nutrient	X	SD	Range[2]
Protein	8.8	0.94	6.9 to 10.7
Starch	70.7	1.5	67.7 to 73.7
Oil	4.0	0.45	3.1 to 4.9

[1]Represents 13,800 grain samples from about 300 genotypes (B. Mahanna, 1997, unpublished data).

[2]$x \pm 2 \times SD$.

The concept of selecting corn hybrids that contain particular genes related to composition has been used by the seed corn industry for many years. In most cases these hybrids were developed from anomalies resulting from identification and exploitation of genetic mutations. From these efforts have come the specialty corn hybrids that have unique physical and chemical characteristics. These hybrids include high lysine, high oil, waxy, sugary, white, brown midrib, quality protein maize, and numerous others. Enhanced nutritional value was the primary reason for developing these hybrids, especially for use in human and nonruminant diets. Many of these hybrids have been available for over 20 yr, so why is there such a renewed interest in these hybrids now? Recent improvements in agronomic and yield performance, in addition to commitments by grain marketers to preserve the identity of specialty corn, have made these corn grains more competitive with regular corn. In addition, as milk production per cow increases, the nutrient density of their diet increases, requiring more expensive supplementation and decreased formulation flexibility. Consequently, nutritionally enhanced corn should have greater economic value in diets for high production.

The nutrient composition of different specialty corns from several sources is listed in Table 2. These data originate from ruminant feeding trials that were conducted from 1971 to 1997. Within each corn type, the studies are ranked by protein content as compared with the normal corn control within each study. Superscripts reflect the similarity of the composition of the specialty corn to that of the normal corn used in

TABLE 2. Nutrient composition of specialty corn grains (percent of DM).

Type[1]	CP	Starch	NDF	Lipid	Lysine	Reference
HL	8.1[2]	. . .	. . .	3.5[2]	0.37[3]	40
HL	9.3[2]	. . .	. . .	. . .	0.41[3]	25
HL	8.9[4]	. . .	. . .	4.5[3]	0.40[3]	9
HL	9.6[4]	. . .	. . .	. . .	0.40[3]	25
HL	9.6[4]	. . .	. . .	4.7[3]	0.38[3]	2
HL	9.8[4]	. . .	. . .	. . .	0.33[3]	27
HL	9.9	. . .	. . .	. . .	0.37	25
HL	10.1[4]	76.1[4]	. . .	. . .	0.35[3]	38
HL	11.3	. . .	. . .	4.8	0.46	32
HL	11.7[3]	. . .	. . .	5.0[3]	0.51[3]	24
FL	11.2[3]	. . .	. . .	4.4[4]	0.35[3]	24
QPM	9.8[3]	. . .	. . .	4.4[3]	0.40[3]	9
HO	7.9[2]	67.5[2]	17.1[3]	6.4[3]	. . .	26
HO	8.9[4]	. . .	13.8[3]	. . .	. . .	14
HO	9.3[3]	67.8[2]	11.8[3]	7.3[3]	0.30[4]	21
HO	9.8[3]	. . .	. . .	10.6[3]	. . .	17
HO	11.1[3]	. . .	19.6[3]	9.1[3]	. . .	4
WX	10.4[3]	. . .	14.3[2]	3.8[2]	0.11[2]	7

[1]HL = High lysine corn, FL = floury corn, QPM = quality protein maize, HO = high oil corn, and WX = waxy corn grain.

[2]Value is lower than regular corn used in the study.

[3]Value is higher than regular corn used in the study.

[4]Value is similar than regular corn used in the study.

the study. Nutrient content within types is variable, differing by as much as 50 to 80%.

High Lysine

Corn with higher concentrations of lysine was originally identified in the early 1960s (30) and has been extensively studied for its use in the diets of nonruminants (22). The recessive opaque-2 gene is specifically responsible for higher lysine concentrations that are the result of smaller amounts of zein protein (especially α-zein) and larger amounts of albumin, globulin, and glutelin proteins (29). Grain yield has been a concern (20), but more recent hybrids have more favorable yield, especially in full-season environments (B. Briggs, 1998, personal communication). The protein and lysine content of high lysine corn is variable (Table 2). On average, the protein content of high lysine corn is nearly the same as that of regular corn, and the lysine content is 54% higher (0.40 vs. 0.26% of DM).

Lysine has been identified as one of the first-limiting AA in dairy diets (36). Essential AA concentrations in normal, high lysine, and high oil corn are presented in Table 3, along with potential milk production when each AA is considered first limiting. Assumptions used in this table are consistent with those reported by Polan (34). Regular corn is most deficient in lysine; each kilogram of corn is able to support the synthesis of 0.60 kg of milk containing 3.1% protein. If the efficiency of dietary lysine conversion to milk lysine remains constant between regular and high lysine corn, high lysine corn could potentially increase milk production by 55%. However, substantial evidence indicates that protein (glutelin) in high lysine corn is more degradable in the rumen than is protein (zein) in regular corn (2, 27, 35, 43). The result is that less of the lysine in high lysine corn is available for intestinal absorption. Redd et al. (35) observed similar abomasal flows of lysine between regular and high lysine corn; however, Ladely et al. (27) found that ruminally undegraded lysine concentrations (percentage of DM) were 28% higher in high lysine corn. Studies with ruminants attribute little nutritional benefit to the lysine portion of high lysine corn (27). Future efforts to improve the lysine value of corn must focus on delivery of lysine to the intestines either through enhanced microbial protein lysine or ruminally undegraded lysine.

Opaque-2 corn is also characterized by a soft endosperm with loosely packaged starch granules (15) that may be more accessible to microorganisms during ruminal fermentation. We recently conducted a study with grain from seven high lysine corn hybrids and one normal hybrid harvested at black layer and five high lysine hybrids and five normal hybrids harvested as dry grain (11). All hybrids examined were commercially available at the time of the study. Dry grain was either finely or coarsely ground, and in vitro ruminal starch digestibility was measured after

6 and 12 h of incubation. Ruminal starch digestibility was higher for every high lysine hybrid compared with regular corn harvested at black layer, for finely ground dry corn, and for coarsely ground dry corn after 12 h of incubation. These results are supported by earlier in situ digestibility work conducted with growing steers (27).

The endosperm of a corn kernel can be divided into floury and horny (flinty) endosperm. The floury endosperm is characterized by larger cells that are soft and opaque (16). Starch granules in these cells are spherical and have space between them. Horny endosperm contains larger and more numerous storage proteins (zeins) and starch granules that are compact, polygonal, and coated with a protein matrix. The soft endosperm is lower in test weight and makes high lysine corn grain more susceptible to kernel damage, disease, and storage losses. This difference is a major reason for attempts of corn breeders to make the kernel more dense; however, such changes may decrease starch digestibility and the nutritional value of corn. Recent challenges from harvesting corn silage that was too mature and contained hard, dry kernels have raised interest in improving starch digestibility in corn silage. Corn silage may be a more appropriate form for high lysine corn because the concern over kernel damage and storage losses is not as great, although lysine degradability may be higher in corn silage.

Few studies have been conducted with lactating dairy cows (Table 4). In an early study, 40 lactating cows were fed combinations of corn grain and silage from high lysine or regular hybrids (2). Milk production and feed intake were not different between hybrids; however, solids-not-fat content was higher with high lysine corn grain. Most notable was an increase in nutrient digestibility (OM, CP, ADF, and N-free extract) of high lysine corn grain that resulted in a higher TDN value for these diets. No differences were observed between corn silages. We recently conducted a similar lactation study using more modern commercial hybrids with 16 cows in a Latin square design (5). Milk production did not differ, but feed intake was 9% higher for cows fed high lysine silage diets. The digestibility of DM and starch was also higher for high lysine silage, which resulted in an 18% increase in digestible DMI. However, DM digestibility was lower for high lysine grain. Ruminal ammonia concentrations were 27% lower for both high lysine silage and high lysine grain diets, which suggests that degradable N was more efficiently used by ruminal microorganisms. No differences were observed for ruminal or fecal pH, or ruminal VFA concentrations. In a subsequent silage study with 50 cows in a block design (R. G. Dado, 1998, unpublished data), intake was not higher for cows fed high lysine silage, but 3.5% FCM was 2.7 kg/d higher compared to regular corn. High lysine corn diets may be most appropriate for feeding situations that require more ruminally digested starch, including rations in early lactation that use dry corn grain. High lysine corn silage may be beneficial to increase the

TABLE 3. Essential amino acid (EAA) concentrations in and potential milk production from regular, high lysine, and high oil corn grain.

	Concentration (% DM)			Potential milk production[1] (kg/kg)		
EAA	Regular[2]	High lysine[3]	High oil[4]	Regular	High lysine	High oil
Arg	0.41	0.62	0.43	2.16	3.21	2.24
His	0.27	0.33	0.32	1.95	2.39	2.30
Ile	0.31	0.33	0.37	1.00	1.06	1.18
Leu	1.13	0.98	1.22	2.18	1.90	2.35
Lys	0.26	0.40	0.28	0.60	0.93	0.65
Met	0.20	0.17	0.20	1.40	1.19	1.43
Phe	0.44	0.45	0.46	1.61	1.63	1.68
Thr	0.31	0.36	0.33	1.32	1.49	1.40
Trp	0.07	0.12	0.07	0.90	1.66	0.97
Val	0.43	0.51	0.49	1.23	1.46	1.42
Total EAA	3.38	4.25	4.17	1.44	1.60	1.57

[1]Potential milk production (kilogram) from each kilogram of corn grain assuming particular EAA is first limiting. Based on EAA content of milk with 3.1% protein; assumes no EAA requirement for non-EAA synthesis and efficiency of conversion of dietary EAA to milk EAA of 56% for all EAA (34).

[2]From Mertz et al. (30); Redd et al. (35); NRC (32); Degussa (13); Hammes (21); Stilborn and Crum (39); Briggs (1997, personal communication).

[3]From Mertz et al. (30); Redd et al. (35); NRC (32); Briggs (1997, personal communication).

[4]From Araba (3); Hammes (21); Stilborn and Crum (39).

TABLE 4. Performance of dairy cows fed high lysine (HL) or regular corn grain or silage.

Diet	Amount in diet (% of DM)	DIM	Milk (kg/d)	FCM[1] (kg/d)	Fat (%)	Protein (%)	DMI (kg/d)	BWC[2] (kg/d)	Reference
Corn grain comparisons									
Regular	36	90	28.4	27.5	3.28	3.22	19.6	. . .	2
HL	36	90	29.6	28.3	3.25	3.38	19.5	. . .	2
Regular	17	91	26.8	29.1	4.02	3.36	24.6	+0.5	5
HL	17	91	26.8	28.8	3.96	3.35	23.9	+0.2	5
Corn silage comparisons									
Regular	40	90	28.4	27.7	3.34	3.32	19.4	. . .	2
HL	40	90	29.6	28.2	3.20	3.28	19.9	. . .	2
Regular	46	91	26.6	28.9	4.02	3.36	23.2	+0.5	5
HL	46	91	27.0	29.1	3.96	3.36	25.3*	+0.2	5
Regular	40	150	30.8	28.5	3.16	3.39	24.6	+0.41	R. Dado, 1998,
HL	40	150	32.6	31.2*	3.37	3.51	21.8	+0.36	unpublished data

[1]3.5% Fat-corrected milk.

[2]Body weight change.

*Two means within the same study differ ($P < 0.05$).

harvesting window for silage and prevent the passage of whole, dry kernels that can occur when corn is too mature.

Many, if not most, studies compare the performance of livestock fed different corn hybrids by using corn of unrelated or unknown genetic background. Consequently, observed performance differences are perhaps relative only to the control corn that was used, whether it be a modern commercial competitor or an outdated internal generic hybrid. Isogenic parent controls are advocated by many researchers to obtain unconfounded effects for the specialty hybrid. However, most of these isogenic controls are not commercially viable hybrids and may not be available in adequate quantities for animal feeding studies. In addition, the specialty corn may have undergone additional rounds of selection since its development and may be quite unrelated to its original parent. Readers of hybrid comparisons need to be aware of the objectives of the study and the quality of the control. An industry standard hybrid that is updated periodically would be beneficial for comparing new hybrids across different studies.

High Oil

Corn hybrids with higher concentrations of oil have received considerable attention recently. Interest in developing high oil corn began as early as 1896 with the concept of “Illinois High Oil” and led to the eventual release of commercial high oil hybrids by Pfister in 1981 (21). In general, high oil corn grain has been reported to contain about twice the amount of oil as regular corn (8 to 10 vs. 4 to 5% of the DM) and about 1 to 2% units more protein (Table 2; 17). In recent attempts to improve grain yields in high oil corn, oil concentrations have decreased to about 7.3%, and protein concentrations have decreased so they are about 0.5% units higher than regular corn (21). Lysine and other essential AA concentrations in high oil corn are slightly higher compared with regular corn (Table 3) because of more germ protein. However, lysine is still markedly deficient for milk production. Because lipid contains about 2.25 times the number of calories as a similar weight of carbohydrate, high oil corn contains about 4% more gross energy than does regular corn. Values reported in Table 2 suggest that high oil corn may contain more NDF than regular corn, which may be a potential limitation to its nutritional value. Higher NDF was also noted in high oil corn silage (17). Morphologically, the high oil kernel contains a larger germ (embryo), which is the major oil-containing component of the seed. High oil corn stover appears to contain similar concentrations of oil compared with regular corn stover; consequently, the difference in oil concentrations between high oil corn and regular corn in corn silage is not as great as the difference in corn grain (17).

Smaller amounts of endosperm in high oil corn kernels result in less starch in both grain and silage compared with normal corn grain and silage (68 vs. 71% of the grain DM; 21). Because oil is not fermentable in the rumen and starch is, a smaller quantity of starch in high oil corn may result in less microbial growth and protein synthesis. This limitation could be countered by adding additional starch sources to the ration (i.e., more total corn grain or other starch sources) and may not be a major concern. In high grain rations, less fermentable starch may actually be a benefit to avoid the acidotic conditions associated with a highly fermentable diet. High oil corn is currently advocated as a replacement for other more expensive oil seeds (e.g., cottonseeds and whole soybeans), and its value is typically calculated based on this replacement.

To increase grain yields, the TopCross™ Grain Production System (Optimum Quality Grains, Des Moines, IA) has been introduced, whereby seed corn companies lease the use of high oil corn pollinators and blend it with their own high yielding hybrids (21). Seed from male-sterile forms of these commercial hybrids (90%) are combined in the bag with the high oil seed (10%). The resulting in-field hybrid retains the grain producing qualities of the origin hybrid and the high oil qualities of the pollinator. Yield reductions, however, still remain; compared with the nonsterile form of the regular hybrid, the high oil combination reduces grain yield from 3 to 5% (17).

Several recent lactation studies have been conducted with high oil grain (Table 5). In each of these studies, high oil corn grain was directly compared with regular corn on an equal weight basis without adjustment for differences in oil, protein, or other nutrients. Milk production was significantly higher (1 kg/d) for high oil corn in only one study (17) and was similar to regular corn for the other studies. Unexpectedly, the study in which a production response was observed was the one with the lowest milk production per cow. Milk composition was similar between corn types except for a slight decrease (–0.07%) in milk protein in a 21-wk study conducted by Dhiman et al. (14). Two studies found increased DMI (2.2 kg/d) for high oil corn diets (4, 26); however, they did not result in higher production or BW gain. Increases in intake were possibly due to lower VFA production in the rumen, which tend to cause cessation of eating (26), or to a reduction in subclinical ketosis (4). Nutrient digestibilities were similar between grain types except for lower DM digestibility (4) and higher starch digestibility noted for high oil hybrids (17). No performance differences have been found with high oil corn as silage for lactating cows (17) perhaps because of the dilution of any oil effects in the kernel by average quality stover.

Other Specialty Corns

Waxy corn was initially utilized in nonfeed industries for adhesives, textiles, and human food (22). Waxy corn contains starch that is nearly 100% amylopectin compared with starch in regular corn that contains about 25% amylose and 75% amylopectin. A high degree of branching, as noted in amylopectin, has been shown to disrupt the granular structure of starch and increase its susceptibility to attack by enzymes and its digestibility in vitro (31). Other constituents of waxy corn appear to be similar to that of regular corn.

TABLE 5. Performance of dairy cows fed high oil (HO) or regular corn grain.

Diet	Amount in diet (% of DM)	DIM	Milk (kg/d)	Fat (%)	Protein (%)	DMI (kg/d)	BWC[1] (kg/d)	Reference
Regular	30	21	39.7	2.43	2.84	19.6	–0.02	4
HO	30	21	40.1	2.40	2.84	21.9*	+0.13	4
Regular	45	49	37.9	3.30	3.04	27.2	–0.62	18
HO	45	49	37.8	3.33	2.98	27.1	–0.49	18
Regular	27	21	34.0	3.42	3.18	21.3	. . .	26
HO	27	21	35.5	3.44	3.20	23.4**	. . .	26
Regular	grain+sil[3]	14	36.5	3.39	3.00[+]	21.7	+0.20	14
HO[2]	grain+sil[4]	14	36.0	3.28	2.93	2.16	+0.19	14
Regular	25	. . .	27.4	3.42	3.12	21.4	. . .	17
HO[2]	25	. . .	28.4*	3.39	3.10	21.4	. . .	17

[1]Body weight change.

[2]Produced by TopCross™ (Optimum Quality Grains, Des Moines, IA) production system.

[3]32% Regular corn grain + 22% regular corn silage.

[4]32% HO corn grain + 22% HO corn silage.

[+]Two means within the same study differ ($P < 0.10$).

*Two means within the same study differ ($P < 0.05$).

**Two means within the same study differ ($P < 0.01$).

The utilization of waxy corn by swine has been evaluated as having little nutritional advantage (22). Studies with ruminants are limited. Waxy corn grain was compared with regular corn grain at 90% of the diet for finishing lambs and steers (7). Average daily gain was higher in all three trials, and feed efficiency was higher in two of three studies with waxy corn; however, the response varied with protein source. A recent report with lactating cows indicated a 4% increase in milk production and no change in milk composition with waxy corn grain (37). No data were presented on starch digestibility or feed intake. Additional research is required to substantiate enhanced performance with waxy corn hybrids. The use of waxy corn in dairy diets may be similar to that suggested for high lysine corn because both appear to have advantages involving starch digestibility.

Quality protein maize (**QPM**) was originally developed to solve some of the handling problems associated with the soft endosperm of high lysine corn (28). The QPM contains modifier genes that convert the soft endosperm to a more flinty form without a substantial loss in lysine content. Quality protein maize contains more gamma-zein than normal or opaque-2 corn (28). Performance of finishing swine was greater for those fed QPM than for those fed regular corn but was similar to that for swine fed high lysine corn (9). The value of QPM for ruminants has not been determined. Increasing the hardness of the grain endosperm via QPM may reduce starch digestibility but may also decrease the metabolism of lysine by ruminal microorganisms and potentially increase absorbable lysine.

Sugary corn is a result of a genetic mutation at a sugary locus on chromosome 4. Three different alleles were examined by Brink (8) that included corn known as sugary, sugary-crown, and sugary-Brawn. All genotypes result in corn grain with higher concentrations of water-soluble carbohydrate and lower concentrations of starch compared with regular corn. The sugary corn kernel contains 10 times more soluble carbohydrate than regular corn, and sugary-Brawn contains about five times more. Only the sugary-Brawn corn appears to produce a plant that has acceptable yield and agronomic traits (e.g., sufficient kernel dry down) to be used on a commercial basis (41). Willcox et al. (44) compared sugary-Brawn corn grain with regular corn for eight lactating cows receiving an alfalfa silage-based diet. Milk production and intake were not different, and milk fat content was lower (–0.2%). Ruminal digestion of starch and DM were higher in sugary-Brawn diets and resulted in higher concentrations of VFA.

Floury-2 corn is a result of another gene mutation that produces a grain similar in composition to opaque-2 corn. When fed to nonruminants, the nutritional value of floury-2 corn grain was intermediate to that of regular or high lysine corn and appeared to be a function of protein quality (24). Performance of ruminants fed this corn is unknown. This author is unaware of any interest among seed companies for the development of this corn; however, some floury-2 germplasm has been used in the development of opaque-2 hybrids (Briggs, 1998, personal communication).

Economic Value: Nutrient Substitution

The long-term viability of specialty corn depends on the value of its nutritional quality compared with the risks associated with possible yield reductions and poor agronomic performance. Assessing the economic value of nutritional quality is difficult. Many factors can influence the value of specialty corn, including the actual nutrient content of the grain; type and production of animals to be fed; the amounts, types, and quality of other feeds included in the diet; the price of alternative feed ingredients; costs associated with changes in feed storage and handling; and the probability of achieving an enhancement in production. If a diet meets the nutrient requirements of an animal fed normal corn, the specialty feed should not increase performance but could lower feed costs if it substitutes for nutrients provided by a more expensive ingredient.

The value of individual nutrients has been used to assign economic value to specialty corn in the past (1, 17, 22). This simple method assumes that a nutrient has a constant value in all feed formulations, which is not true for all nutrients and lactating dairy diets. However, this method provides a quick approximation of the maximum substitution value of specialty corn. The economic value of three specialty corn grains compared with regular corn is listed in Table 6. These values are based on the nutrient values presented in Table 6 and the mean nutrient composition of these corns from Table 7. Two values are given for high lysine corn. The first is for lysine corn that has no lysine advantage in ruminants (low ruminal bypass lysine) and may approximate currently available high lysine hybrids. The second lysine corn, called enhanced high lysine, assumes that the RUP content (percentage of CP) of high lysine is equal to normal corn and results in enhanced bypass lysine. This second high lysine corn is a specialty corn that may be

TABLE 6. Economic value of specialty corn grains in dairy diets as determined by nutrient substitution or least-cost formulation compared with regular corn.[1]

	Increased value		Break-even[2] yield reduction	
Method	$/kg of DM	$/wet bu	bu/ac	%
Nutrient substitution[3]				
High lysine[4]	0.0080	0.18	9.4	7
Enhanced high lysine[5]	0.0111	0.25	12.7	9
High oil	0.0177	0.40	19.1	14
High protein[6]	0.0139	0.31	15.5	11
Least cost formulation[7]				
Enhanced high lysine				
Mean	0.0070	0.16	8.2	5.9
32 kg/d of Milk	0.0006	0.01	0.8	0.6
41 kg/d of Milk	0.0148	0.33	16.4	11.7
50 kg/d of Milk	0.0123	0.28	13.9	9.9
High oil				
Mean	0.0067	0.15	7.8	5.6
32 kg/d of Milk	0.0034	0.08	4.2	3.0
41 kg/d of Milk	0.0077	0.17	9.0	6.4
50 kg/d of Milk	0.0131	0.29	14.7	10.5
High protein				
Mean	0.0085	0.19	9.8	7.0
32 kg/d of Milk	0.0135	0.30	15.1	10.8
41 kg/d of Milk	0.0046	0.10	5.5	3.9
50 kg/d of Milk	0.0053	0.12	6.4	4.6

[1]Based on nutrient composition of regular and specialty corns.

[2]Assumes input costs do not change with the specialty corn compared with regular corn. Corn grain = $98/tonne; 8.9 tonne/ha.

[3]Ruminally degradable carbohydrate = $0.114/kg, CP = $0.548/kg, oil = $0.55/kg, and lysine = $2.2/kg.

[4]Reflects nutrient value of current hybrids containing low ruminally undegradable lysine.

[5]Reflects nutrient value of possible future hybrids containing high ruminally undegradable lysine.

[6]Possible future hybrid containing 3% units more protein than regular corn.

[7]Potential cost savings from 352 formulations designed for lactating cows using a diversity of ingredients, prices, and levels of milk production.

available in the near future. The high protein corn is hypothetical in that it is not commercially available; however, its nutrient composition is realistic given earlier comments on protein selection, and it is a likely hybrid for the future as well.

In this scenario, high lysine contains more ruminally digestible carbohydrate than does regular corn (Table 7), which is reflected by higher NFC and NE_L values. High oil contains 0.5% units more protein and 3% more fat but less NFC and more NDF. High protein contains 3% units more protein, less NFC, and less lysine as a percentage of CP. On a nutrient substitution basis, high oil corn has the greatest value because of the high value of protein and oil (Table 6). Breakeven yield reductions are useful criteria for comparing the net effect of nutritional quality and yield performance. Under nutrient substitution, all corns can tolerate a yield reduction of 5% and remain advantageous (Table 6).

Economic Value: Least Cost Positioning

A least-cost ration formulation via linear programming is the best way to assess the economic value of specialty corns in different feeding situations because it overcomes the assumption that nutrients have constant value. Some nutrients, such as fat, are only needed in certain diets and have little value in diets in which they are not required. To determine the best economic position of specialty corns, 352 least-cost formulations (88 per corn type) were performed for lactating dairy cows using regular, enhanced high lysine, high oil, and high protein corn (Table 7). Data collected included ingredient composition and daily ingredient cost for each formulation. Ingredients used were corn grain, alfalfa silage, corn silage, soybean meal, a bypass protein source, tallow, bypass fat, and other minerals and vitamins. Prices for corn grain, alfalfa silage, soybean meal, bypass protein, and tallow were varied across reasonable current market

TABLE 7. Nutrient composition of corn grain used in economic comparisons.

	DM (%)				
Nutrient	Regular	High lysine[1]	Enhanced high lysine[2]	High oil	High protein[3]
CP	8.8	8.8	8.8	9.3	11.8
NE_L, Mcal/kg	1.96	2.07	2.07	2.09	1.98
NFC[4]	76	78	78	73	73
Fat	4	4	4	7	4
NDF	8.7	8.7	8.7	10.5	8.7
Lysine	0.26	0.40	0.40	0.28	0.30
RUP-Lysine[5]	0.13	0.13	0.20	0.14	0.15
Methionine	0.20	0.17	0.17	0.20	0.25
RUP-Methionine	0.10	0.10	0.08	0.10	0.12
RUP, % of CP	50	32	50	50	50
RDNFC,[6] % of NFC	84	92	92	84	84

[1]Reflects nutrient content of current hybrids containing low ruminally undegradable lysine.

[2]Reflects nutrient content of possible future hybrids containing high ruminally undegradable lysine.

[3]Possible future hybrid containing 3% units more protein than regular corn.

[4]Nonfiber carbohydrate.

[5]Ruminally undegradable protein-lysine and RUP-methionine are the concentrations of lysine and methionine in the dietary DM that escape ruminal degradation.

[6]Ruminally degradable NFC.

ranges. Requirements were varied by altering cow age, stage of lactation, and production. Alfalfa quality was varied as was the ratio of alfalfa to corn silage. A commercial least-cost formulator was used (12).

The mean reduction in daily feed ingredient cost was similar for each specialty corn. The savings compared with regular corn was \$0.045, \$0.043, and \$0.041 per cow for enhanced high lysine, high oil, and high protein, respectively. However, variation among formulations was significant. Specialty corns were most valuable in nutrient dense diets because of either high milk production (Figure 1) or reduced feed intake. Specialty corns were also more valuable in high alfalfa diets. The specialty corn with the most value at low to moderate milk production (23 or 32 kg/d) was high protein corn. High lysine and high oil corn had little value (<\$0.02/d) at these levels of production. High lysine corn was most valuable at high milk production (41 kg/d), and high oil corn was most valuable at very high milk production (50 kg/d). The values for each corn per unit of corn are summarized in Table 6. High protein corn was the most stable in value across ingredient price changes. At high milk production, the high lysine corn value was sensitive to alfalfa price (negative relationship) and soybean meal price (positive relationship); high oil corn value was sensitive to corn price (negative relationship) and tallow price (positive relationship). The quantity of high oil corn that could be added to the formulations to keep added vegetable fat to amounts <0.7 kg/d was limited.

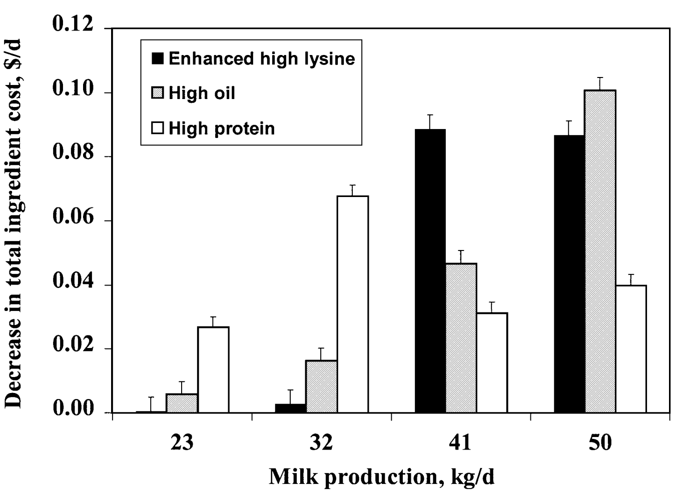

Figure 1. Decrease in total feed ingredient costs when specialty corn grains replace regular corn in diets formulated for lactating dairy cows at different levels of milk production. Ingredients used in formulation were alfalfa silage, corn silage, corn grain, soybean meal, an RUP source, tallow, a ruminally undegradable fat source, minerals, and vitamins. Each bar represents the mean of 22 formulations and corresponding standard error.

Total feed ingredient costs that used each corn type as the sole corn source across an entire lactation for cows with different milk production are listed in Table 8. All specialty corns reduced total feed costs compared with regular corn when the price of each

TABLE 8. Total feed ingredient costs of diets using a specialty corn grain across an entire lactation for cows with different milk production.[1]

	Milk production[2] ($ per cow per lactation)			
Corn type	7705 kg	9520 kg	11,335 kg	13,150 kg
Regular	939	1087	1230	1323
Enhanced high lysine[3]	935	1072	1206	1293
High oil	933	1076	1212	1300
High protein[4]	923	1071	1215	1310

[1]Ingredient costs: corn = $118/tonne, alfalfa = $132/tonne (hay equivalent), soybean meal = $248/tonne, and tallow = $385/tonne. Diets were overformulated by 4.5 kg/d of milk.

[2]Kilograms per lactation.

[3]Reflects nutrient value of possible future hybrids containing high amounts of ruminally undegradable lysine.

[4]Possible future hybrid containing 3% units more protein than regular corn.

was the same. However, high protein corn is the most economical specialty corn for herds producing <9500 kg of milk per lactation because daily production during 54% of the lactation is <32 kg/d. Enhanced high lysine corn is the most economical corn for herds producing >9500 kg of milk. High oil corn is best limited for cows producing >50 kg/d. Even in high producing herds (>13,150 kg/lactation) daily milk production exceeds 50 kg/d during only 29% of the lactation assuming a lactation persistency of 91%.

Based on these findings, the most valuable nutrient in corn for most US dairy herds is protein, because current average milk production in our herds is <9500 kg per lactation. Increasing the protein content of corn has been a major priority for breeders in the past, and such efforts should be continued. Future protein requirements for lower producing cows may be described in terms of specific AA. If this occurs, increases in generic protein will not be important, but increases in specific limiting AA will be important. A decrease in certain AA to lower the amount of fecal N for efficiency and environmental reasons may also be beneficial. Emphasis should continue to be placed on increasing the lysine content of corn, especially the lysine that escapes ruminal degradation. Both undegraded lysine and oil will become more valuable selection criteria as milk production of US herds continues to increase.

IMPLICATIONS

Specialty corn grain hybrids have been developed that contain higher concentrations of certain nutrients compared with regular corn. Nutrients with substantial value in dairy diets include protein, ruminally undegraded lysine, oil, and P; efforts should continue to increase these nutrients in corn through traditional selection programs with commercial hybrids, through specialty hybrids, and through transgenic technology. Specialty corns obtain most of their value in diets by replacing nutrients from more expensive ingredients. High oil corn can be used most favorably in diets of high producing cows (>50 kg/d). High lysine corn currently is of limited value until a greater percentage of the lysine escapes ruminal degradation. High protein corn would be of greatest economic benefit in diets of cows producing low to moderate amounts of milk (<32 kg/d).

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