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Invited review: The use of distillers products in dairy cattle diets

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ABSTRACT

Distillers grains with solubles (DGS) is the major coproduct of ethanol production, usually made from corn, which is fed to dairy cattle. It is a good protein (crude protein, CP) source (>30% CP) high in ruminally undegradable protein (~55% of CP) and is a good energy source (net energy for lactation of approximately 2.25 Mcal/kg of dry matter). The intermediate fat concentration (10% of dry matter) and readily digestible fiber (~39% neutral detergent fiber) contribute to the high energy content in DGS. Performance was usually similar when animals were fed wet or dried products, although some research results tended to favor the wet products. Diets can contain DGS as partial replacement for both concentrates and forages, but DGS usually replaces concentrates. Adequate effective fiber was needed to avoid milk fat depression when DGS replaced forages in lactating cow diets. Nutritionally balanced diets can be formulated that contain 20% or more of the diet dry matter as DGS. Such diets supported similar or higher milk production compared with when cows were fed traditional feeds. Although DGS can constitute more than 30% of diet dry matter, gut fill may limit dry matter intake and production in diets with more than 20% wet DGS and that also contain other moist feeds. The fiber in DGS, which often replaces high-starch feeds, does not eliminate acidosis but minimizes its problems. Distillers solubles, which are often blended with distillers grains to provide DGS, can be fed separately as condensed corn distillers solubles. Other distillers coproducts besides DGS such as high-protein distillers grains, corn germ, corn bran, and low-fat distillers grains are becoming available.
Key words: distillers grains, dairy cattle

INTRODUCTION

The supply of ethanol coproducts (byproducts) has greatly increased in recent years with the expansion of fuel ethanol production. Before that time, only DGS from food ethanol production was available. The major coproduct is distillers grains with solubles (**DGS**), which can be fed in both wet and dried forms, but other products such as condensed corn distillers solubles (**CCDS**), corn germ, and potential new products that are becoming available will be mentioned where data on such products are available. Although the main emphasis of this review is on feeding the milking herd, the use of ethanol coproducts in diets of calves, growing heifers, and dry cows will also be discussed. Most of the ethanol coproducts are currently available as DGS but a wide array of distillers coproducts will be available in the future. Coproducts that result when fermenting other grains or other feed sources will be mentioned, although at the present time research data are limited with many of those sources. Whenever possible, peer-reviewed literature was used in this review; but much of this research to date has been published in abstract form.

NUTRIENT CONTENT OF ETHANOL COPRODUCTS

Distillers grains have been fed for more than 100 yr (see Loosli et al., 1952); however, it is only during recent years that large quantities have become available and at competitive prices. In addition, the products available today usually contain more protein and energy (Birkelo et al., 2004) than older "book values," even more than listed in the recent dairy NRC (2001), and can be of uniformly good quality. This reflects the improved fermentation efficiency of the new-generation ethanol plants (Spiehs et al., 2002).

A committee of the American Feed Ingredient Association recently published a report of recommended methods of analyses for distillers products (Thiex, 2009). Nutrient content of DGS and some other corn distillers coproducts are presented in Table 1. These tabular values reflect primarily those reported in the dairy NRC (2001) as modified by more recently reported analytical information such as data from Spiehs et al. (2002) for new-generation DGS, Birkelo et al. (2004) for the energy values of distillers grains, and the University of Minnesota Web site (University of Minnesota, Department of Animal Science, 2009; www.ddgs.umn.edu) that is updated regularly based on data from nearly 50 ethanol plants primarily in the Upper Midwest states. The DGS of today contain more protein, energy, and

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Table 1. Nutrient content (% of DM unless otherwise noted) of corn dried distillers grains with solubles (DDGS) and several other corn distillers grains coproducts

	Product				
Item	DDGS[1]	CCDS[2]	Bran[3]	Germ[3]	HPDDG[3,4]
CP	30.8	18.5	15.3	17.4	44.6
RUP, % of CP	55.0	30.0		28.0	
NE_L, Mcal/kg	2.26	2.03	2.06	2.53	2.27
NE_M, Mcal/kg	2.07	2.19	2.20	2.75	2.20
NE_G, Mcal/kg	1.41	1.51	1.50	1.96	1.50
NDF	39.0	20.0	21.9	30.1	27.3
ADF	16.1	5.0	7.4	15.1	20.4
Ether extract	11.2	21.5	9.5	17.4	4.2
Ash	5.7	12.5	3.8	6.0	1.9
Calcium	0.05	0.30	0.04	0.02	0.02
Phosphorus	0.79	1.35	0.76	1.58	0.44
Magnesium	0.31	0.60	0.35	0.68	0.11
Potassium	1.02	1.70	1.38	1.77	0.42
Sodium	0.26	0.23	0.67	0.01	0.14
Sulfur	0.69	0.37	0.82	0.22	0.85

[1]Most data are from NRC (2001), Spiehs et al. (2002), Birkelo et al. (2004), and University of Minnesota, Department of Animal Science (2009).

[2]Condensed corn distillers solubles; data from Bharathan et al. (2008) and www.DakotaGold.com.

[3]Data from Tedeschi et al. (2009) and www.DakotaGold.com.

[4]High-protein dried distillers grains.

available phosphorus than did distillers grains from older ethanol plants, which reflects increased fermentation efficiency in today's ethanol plants. Distillers grains from new-generation plants contain virtually no starch compared with as much as 5 to 10% starch in DGS from older, less-efficient ethanol plants. Corn DGS contains relatively high amounts of biologically available phosphorus (Mjoun et al., 2008), which can be an asset (if additional phosphorus is needed in diets) or a liability (if excess phosphorus in manure needs to be disposed of). Sulfur content is usually of no concern unless one is feeding very large amounts of DGS; however, there have been reports of high levels of sulfur (as much as 1%) in DGS from some ethanol plants. In such situations where a high sulfur content is coupled with high intake of DGS (e.g., in which beef cattle were consuming 40% DGS), polioencephalomalacia-like symptoms may occur (NRC, 2001). Recent surveys (Schingoethe et al., 2008) indicate that an average of 0.5 to 0.7% sulfur in DGS may be more the norm than the NRC (2001) value of 0.44%. Higher sulfur content may be related to amounts of acid used in pH control and cleaning operations of ethanol plants that is added to the DGS. In some cases, high sulfur content of the water used may also be a contributor.

Virtually all of the distillers grains available today is as distillers grains with solubles but this may change in the future as processors do more fractionating of the DGS. The composition of corn distillers grains changes slightly depending on how much solubles are added (Martinez-Amezcua et al., 2007; Cao et al., 2009). Distillers grains without solubles has slightly higher CP, lower fat content, and a lower phosphorus content (~0.4%) because the solubles are quite high in phosphorus (usually 1.3 to 1.5%) and usually a lower sulfur content without the solubles (Cao et al., 2009). Most animal performance studies use data for distillers grains with or without solubles interchangeably. If a DGS product contains substantially more fat (e.g., >15%) or phosphorus (e.g., >1.0%) than the values listed in Table 1, it is likely that more than normal amounts of distillers solubles were blended with the distillers grains or that the processor had problems with separation of materials during the handling of solubles. When Noll et al. (2007) added incremental amounts from 0 to 100% of the solubles generated from a batch of distillers grains back to the distillers grains, the fat content increased from 8.9 to 11.7% of dry matter. Phosphorus and sulfur contents likewise increased, whereas protein decreased slightly. When Cao et al. (2009) added CCDS to dried or wet distillers grains at ratios up to 40% of the blend DM (which is more CCDS than is usually blended with distillers grains to make DGS), CP decreased from 34.6 to 30.3%, whereas fat, phosphorus, and sulfur increased. Such variations illustrate the importance of obtaining analytical data on the specific product received from a supplier and the importance of suppliers providing uniform, standardized products.

Ruminally undegradable protein and RDP fractions of dietary protein are important considerations in formulating diets for dairy cattle, especially for high-producing dairy cows. Corn DGS is a good source of

RUP, usually ranging between 47 and 64% of the CP as RUP for higher quality DGS, with wet DGS usually 5 to 8% lower in RUP than dried DGS (Firkins et al., 1984; Kleinschmit et al., 2007a). However, if RUP values for DGS are unusually high (e.g., >80% of CP; Kleinschmit et al., 2007a), it may be advisable to check for heat-damaged, undigestible protein. The highly exposed epsilon amino group on lysine is quite susceptible to heat damage and complexing with sugars via the Maillard reaction (Choi et al., 1949). As in other corn products, lysine is the first-limiting amino acid in corn DGS although DGS is a good source of methionine. Limited data (Kleinschmit et al., 2006, 2007a,b) indicate that higher quality DGS products may contain more available lysine than lower quality products. In fact, a recent survey of dried DGS available from a large number of ethanol plants in the Midwest (University of Minnesota, Department of Animal Science, 2009; www.ddgs.umn.edu) indicated higher concentrations of lysine (3.15% of CP) compared with that (2.24% of CP) listed in the latest dairy NRC (2001). This may indicate an overall improvement in the ethanol industry processing methods that minimize heat damage to DGS. Although a golden-yellow color may be a good indication of quality for DGS, research data from Belyea et al. (2004) indicated that color is sometimes (e.g., Powers et al., 1995) but often not (Kleinschmit et al., 2007a) an accurate indicator of protein quality.

New-generation DGS contain more energy than older "book" values. Research by Birkelo et al. (2004) indicated that wet corn DGS contained approximately 2.25 Mcal/kg of NE_L, 15% more energy than published in the dairy NRC (2001) for dried DGS. This likely reflects a higher energy value for newer generation distillers grains and does not necessarily reflect higher energy in wet compared with dried DGS; that is a separate comparison that has not been made. At least a part of this high-energy content in DGS is due to the fat, whereas some can be attributed to the highly digestible fiber in DGS.

Distillers grains contain large amounts of NDF but low amounts of lignin, which allows the NDF in DGS to be quite digestible (62 to >71% digestible; Birkelo et al., 2004; Vander Pol et al., 2009). Although most DGS contains 38 to 40% NDF, it is not unusual for some sources of DGS to contain less than that. Such readily digestible fiber sources can partially replace forages as well as concentrates in diets of dairy cattle; however, for lactating cows it is recommended that DGS replace concentrate ingredients in the diet, not forage ingredients. Because of the small particle size, DGS contains little effective fiber. Based on procedures of Santini et al. (1983), DGS contains only 3.4 to 19.8% physically effective NDF (Kleinschmit et al., 2007a), which is not sufficient to prevent milk fat depression (Cyriac et al., 2005). Nonforage fiber sources such as DGS can supply energy needed for lactation or growth without the ruminal acid load that often occurs when rapidly fermented starchy feeds are consumed (Ham et al., 1994).

Less information is available about the nutrient content of DGS produced from other crops such as wheat, barley, triticale, or sorghum. However, data available indicate that the composition usually reflects the nutrient content of the grain after removal of starch via fermentation to ethanol. Thus, the concentrations of protein, fat, fiber, and other nutrients in the DGS from various grain sources usually reflect proportionately increased concentrations of those components relative to the starting grain after starch removal (Lodge et al., 1997; Mustafa et al., 2000; Stein and Shurson, 2009). For instance, wheat and barley DGS are usually higher in protein but lower in fat and energy than corn DGS, whereas sorghum DGS will be higher or lower in protein than corn DGS, depending on the source used.

RESPONSE OF LACTATING COWS TO DISTILLERS GRAINS

More than 24 research trials with more than 100 treatment comparisons were conducted between 1982 and 2005 in which corn distillers grains, either wet or dried, were fed to lactating cows. Table 2 is an abbreviated summary of the meta-analysis conducted by Kalscheur (2005), which is similar to the recent results of Hollmann et al. (2007) that summarized much of the same data. Other studies conducted since the summary by Kalscheur (2005) are also discussed, especially if results differ. Amounts of DGS fed ranged from 4.2% of total diet DM (Broderick et al., 1990) to 41.6% of DM (Van Horn et al., 1985). The lactational response to feeding various amounts of DGS, as well as the response to wet versus dried DGS, is covered later in this review.

Production was the same as or higher when feeding DGS compared with feeding control diets in virtually all experiments except, possibly, when feeding large amounts (i.e., 30% or more of diet DM) as wet DGS (Kalscheur, 2005). Part of the additional production due to DGS may have been attributable to slightly more energy from a slightly higher fat content in DGS diets because the fat content of diets was not always balanced across diets in all experiments. However, in experiments such as those by Pamp et al. (2006) that compared DGS to soybean protein as the protein supplement, production was similar or higher, even when DGS and soybean-based diets were formulated to be equal in RUP and fat. Production was similar when feeding whiskey DGS or fuel ethanol DGS (Pow-

Table 2. Dry matter intake, milk yield, milk fat, and protein content when feeding cows diets containing wet or dried corn distillers grain with solubles[1]

Inclusion level, % of DM	DMI, kg/d	Milk, kg/d	Fat, %	Protein, %
0	22.1[b]	33.0[ab]	3.39	2.95[a]
4–10	23.7[a]	33.4[a]	3.43	2.96[a]
10–20	23.4[ab]	33.2[ab]	3.41	2.94[a]
20–30	22.8[ab]	33.5[a]	3.33	2.97[a]
>30	20.9[c]	32.2[b]	3.47	2.82[b]
SEM	0.8	1.4	0.08	0.06

[a–c]Values within a column followed by a different superscript differ ($P < 0.05$).

[1]Adapted from Kalscheur (2005).

ers et al., 1995). In both cases, production was higher than with the soybean meal control diet. However, milk production was lower when those researchers fed a DGS product that was darker and possibly heat-damaged compared with when a lighter, golden-colored DGS was fed but still similar to production when feeding soybean meal. Milk production was higher when feeding DGS products than when feeding the soybean meal-based control diet (Kleinschmit et al., 2006). In that trial, 2 specially processed DGS products intended to have even better quality were evaluated with only small differences in response attributable to the improved DGS quality.

Many research trials are of relatively short duration such as 4- or 5-wk periods in Latin square-style experiments. Dairy producers are likely to be more concerned about long-term responses and wonder if the shorter term research experiments accurately reflect the response expected when feeding DGS continuously for long periods. Therefore, an experiment was conducted in which cows were fed 15% of diet DM as wet DGS for the entire lactation, during the dry period, and into the second lactation. After the first year, there were no differences in production (31.7 and 33.6 kg/d for control and wet DGS), whereas percentage of fat (3.75 and 4.07), percentage of protein (3.29 and 3.41), and feed efficiency (1.30 and 1.57 kg of FCM/kg of DMI) were greater for cows fed wet DGS (Mpapho et al., 2006). Reproductive efficiency and cow health were similar for both dietary groups; however, the response in feed intake and milk production tended to be more consistent when fed DGS, possibly reflecting fewer digestive problems. Response during the dry period and first 70 d of the next lactation was similar for control and wet DGS fed cows (Mpapho et al., 2007).

Production responses to DGS are usually similar with all forages (Kalscheur, 2005), although Kleinschmit et al. (2007b) observed slightly greater production when 15% dried DGS was fed in high alfalfa versus high corn silage diets. This likely reflected an improved amino acid status with the blend of alfalfa-DGS proteins versus a diet containing predominantly corn-based proteins. The summary by Hollmann et al. (2007) likewise showed a greater response to DGS with alfalfa-based than with corn silage-based diets. Although there may be differences in the protein quality of various sources of DGS (Kleinschmit et al., 2007a), differences in yields of milk and milk protein will likely be slight, unless a product is greatly heat-damaged.

Production is usually similar or higher when DGS replaces some of the starch in diets of dairy cattle. The starch content of diets is decreased from the typically 23 to 26% starch to sometimes less than 20% starch when fed DGS. Ranathunga et al. (2008) demonstrated that replacing incremental amounts of starch in diets from 29% starch in a diet that did not contain DGS to only 19.9% starch in a diet containing 21% dried DGS had no effect on milk production or composition but tended to improve feed efficiency. All diets contained 49% forage and were balanced for fat content (4.7% of DM) in that study, such that the response measured was a response to DGS fiber versus corn starch.

Fewer data are available regarding the production response to DGS obtained from other grains. Research indicated that the energy value of wheat-based DGS was at least equal to that of barley grain for feedlot cattle (Beliveau and McKinnon, 2008), and triticale DGS supported similar milk production to corn DGS (Greter et al., 2008). Diets containing barley DGS supported similar milk production to soybean meal-based diets (Weiss et al., 1989). When sorghum DGS was fed, production (31.9 kg/d) tended to be less than when corn DGS was fed (33.2 kg/d; Al-Suwaiegh et al., 2002). This result agreed with data that indicate that sorghum DGS is slightly less digestible than was corn DGS (Al-Suwaiegh et al., 2002).

MILK COMPOSITION WHEN FEEDING DISTILLERS GRAINS WITH SOLUBLES

The composition of milk is usually not affected by feeding DGS unless routinely recommended ration formulation guidelines are not followed, such as feeding sufficient amounts of functional fiber. Field reports of milk fat depression when diets contained more than 10% of ration DM as wet DGS are not supported by research results. Research showed no decreases in milk fat concentration when diets contained wet or dried DGS at any level, even as high as 40% of DMI (see Table 2). In fact, the milk fat concentration was usually numerically highest for diets containing DGS. Milk fat yields were also evaluated (Kalscheur, 2005) and reflected what would be indicated by multiplying the milk yields by the fat percentages listed in Table 2. Most of those studies were conducted during early to mid lactation, thus the data in Table 2 are typical for cows during these stages of lactation. In studies that included cows fed DGS during the entire lactation (Mpapho et al., 2006), milk fat tests averaged 4.07% for Holsteins and Brown Swiss, with the typical lower fat percentages occurring during the times of greater milk production in early lactation and higher fat tests in later lactation. Kleinschmit et al. (2006) and Pamp et al. (2006) observed fat tests of 3.54 to 3.60% for mid-lactation Holsteins, and Kleinschmit et al. (2007b) observed an average of 3.72% fat for late-lactation Holsteins.

Milk fat content was lower only when DGS-supplemented diets that contained less than 50% forage (Kalscheur, 2005) and 22% forage NDF were fed. That result suggests why field observations of milk fat depression may have occurred. Because DGS contains an abundance of NDF, one may be tempted to decrease the amounts of forage fed when formulations indicate more than sufficient amounts of NDF. However, the small particle size of DGS means that its effective fiber—as measured by ability to stimulate chewing or rumination as well as by the ability to maintain milk fat (Grant, 1997)—is not as great as that of the forage fiber it replaced. Research by Leonardi et al. (2005), Cyriac et al. (2005), and Hippen et al. (2007) support observations from the meta-analysis (Kalscheur, 2005). Cyriac et al. (2005) observed a linear decrease in milk fat concentration while milk production remained unchanged when cows were fed 0, 7, 14, and 21% of DM as dried DGS in place of corn silage, even though dietary NDF content remained unchanged at 32% of DM. The control diet contained 40% corn silage, 15% alfalfa hay, and 45% concentrate mix. Thus, the key to maintaining milk fat tests is to feed sufficient amounts of effective fiber.

Other situations exist in which milk fat depression may occur when feeding DGS. The recent report by Owens et al. (2009) indicated that when diets contained monensin—a compound known to slightly decrease milk fat percentages under some situations (Dubuc et al., 2009)—feeding DGS in combination with high-moisture corn decreased milk fat content and yield. Such decreases did not occur when the DGS was fed with dry corn or when high-protein, dried distillers grains were fed with dry or high-moisture corn. Because all diets were balanced for fat content using a saturated fat source for the nondistillers diets, the milk fat depression with the high-moisture corn-DGS combination implies a possible interaction of increased ruminal starch fermentability with unsaturated fatty acids from the DGS, at least in the presence of monensin. One must be cognizant of the total fat in the diet, not just fat from DGS (NRC, 2001).

The fatty acid content of milk fat when cows are fed DGS is not expected to be affected greatly but has been evaluated in a few studies. Because the fat in DGS, especially corn DGS, is quite unsaturated with typically more than 60% linoleic acid, it is logical to expect a modest increase in concentrations of unsaturated fatty acids in the milk produced as observed by Schingoethe et al. (1999). Leonardi et al. (2005) and Anderson et al. (2006) also reported modest increases in the *cis*-9, *trans*-11 conjugated linoleic acid (**CLA**) and its precursor, vaccenic acid (*trans*-11 C18:1), that are beneficial to humans for improved health status (Bauman et al., 2006). However, they observed little change in fatty acids such as *trans*-10, *cis*-12 CLA that are often associated with milk fat depression (Baumgard et al., 2002).

Milk protein content is seldom affected by feeding DGS unless protein is limiting in the diet. Then, the lysine limitation in DGS may cause a slight decrease in milk protein content (Nichols et al., 1998; Kleinschmit et al., 2007b). This effect may be more noticeable in diets that contain more than 30% DGS (Kalscheur, 2005), reflecting the high RUP and lysine limitation in DGS. The meta-analysis (Kalscheur, 2005) indicated slightly higher milk protein percentages when feeding blends of alfalfa and corn silage with DGS than with either forage alone, but milk protein yields were the same for all forage combinations. Kleinschmit et al. (2007b) observed no differences in milk protein content or yield when feeding 15% dried DGS in diets where the forage varied from all alfalfa to all corn silage. However, the amino acid balance was improved with the alfalfa diet indicating a more desirable blend of amino acids in the diet compared with a high corn-based product diet with corn silage, DGS, and corn, which was limiting in lysine. It may be logical to speculate that the energy in DGS may also stimulate milk protein synthesis by increasing essential amino acids available to the mammary gland as the result of increased ruminal microbial protein synthesis; however, we are not aware of research testing this specific point.

Feeding distillers products likely does not affect milk flavor or processing of the various products produced from the milk. The authors are not aware of any research evaluating the effects of feeding DGS on milk quality; however, there is no reason to expect problems.

WET VERSUS DRIED DISTILLERS GRAINS WITH SOLUBLES

The response to wet or dried DGS is usually considered equal. However, few experiments actually compared wet versus dried DGS; most experiments simply compared DGS to a control diet. When Al-Suwaiegh et al. (2002) compared wet versus dried corn or sorghum DGS for lactating cows, they observed similar production for both wet and dried DGS but a tendency for more milk with corn versus sorghum DGS. Anderson et al. (2006) observed greater production when feeding either wet or dried DGS compared with feeding the control (corn-soybean meal) diet, a tendency for greater production when feeding wet DGS instead of dried DGS, and a tendency for greater production when feeding 20% of the ration DM as DGS versus 10%, either wet or dried.

The main considerations regarding the use of wet versus dried DGS are handling and cost. Dried products can be stored for extended periods, can be shipped greater distances more economically and conveniently than wet DGS, and can be easily blended with other dietary ingredients. Feeding wet DGS avoids the cost of drying the product, and wet DGS will mix well directly into a TMR. However, wet DGS will not remain fresh and palatable for extended periods; 5 to 7 d is the norm, possibly less in hot weather and a little longer in cooler weather. Claims are made for some silage additives to extend the storage time of wet DGS (Spangler et al., 2005). Researchers at South Dakota State University and elsewhere have successfully stored wet DGS for more than 6 mo in silo bags when the wet DGS was stored alone or blended with soyhulls (Anderson et al., 2009), corn silage (Kalscheur et al., 2003), or beet pulp (Kalscheur et al., 2004). Some field reports indicate successful preservation of wet DGS for more than 1 yr in silo bags.

OPTIMAL AMOUNTS OF DISTILLERS GRAINS WITH SOLUBLES TO FEED

The review by Kalscheur (2005; see Table 2 for a summary) indicated that milk production was maintained with increasing amounts of DGS in the diet and numerically the highest when fed at up to 30% of diet dry matter as dried DGS. For wet DGS, the highest production was achieved at 20% of diet dry matter. At more than 20 to 25% as wet DGS, gut fill may have limited DMI in some studies in which the diet included other moist feeds such as corn silage because the diets contained less than 50% DM (NRC, 2001). It was only when feeding about 40% DGS, wet or dried, that production declined. This was further illustrated by the recent study of Janicek et al. (2008), which reported a linear increase in milk production when going from 0 to 30% dried DGS in diets. Thus, more than the 5 to 10% DGS that is often fed by many dairy producers can easily be included in dairy cattle diets.

A practical and appropriate nutrient management approach is to feed 20% of the diet dry matter as wet or dried DGS. Researchers (e.g., Nichols et al., 1998; Anderson et al., 2006; Kleinschmit et al., 2006) demonstrated in several experiments that dairy cows can easily consume 20% of the ration DM as distillers grains. Based on typical feed intakes of lactating cows, this is approximately 4.5 to 5.5 kg of dried DGS or 15 to 17 kg of wet DGS per cow daily. There were no palatability problems and one can usually formulate nutritionally balanced diets with up to that level of distillers grains in the diet using most combinations of forages and concentrates. For instance, with diets containing 25% of the DM as corn silage, 25% as alfalfa hay, and 50% as concentrate mix, the DGS can replace most, if not all, of the protein supplement such as soybean meal and a significant amount of the corn that would normally be in the grain mix. This was illustrated in the experiment by Anderson et al. (2006) in which feeding 20% of the diet DM as wet or dried DGS replaced 25% of the corn and 87% of the soybean meal that was fed in the control diet. With diets that contain higher proportions of corn silage, even greater amounts of dried DGS may be used; however, the need for some other protein supplement, protein quality (e.g., lysine limitation), and phosphorus concentration may become factors to consider. With diets containing higher proportions of alfalfa, less than 20% DGS may be needed to supply the protein required in the diet. No strong nutritional advantages occur with feeding more than 20% distillers grains, but the possibility of feeding excess protein or phosphorus may occur. If feeding more than 20 to 25% of dry matter as wet DGS with other moist feeds such as corn silage also in the diet, gut fill may limit DMI and milk production (Hippen et al., 2003; Kalscheur, 2005). Such diets often contain less than 50% DM, a condition that may limit DMI (NRC, 2001), especially when the moist feeds are fermented. However, grazing cows often consume very large quantities of 20% DM fresh forage, but we are not aware of grazing studies that included wet DGS or extensive amounts of other moist feeds.

The economics of ration formulation often indicates that it is most profitable to feed as much DGS as possible. Indeed, beef cattle have been successfully fed 50% or more of diet DM as wet or dried DGS (Klopfenstein et al., 2008). Admittedly, feeding very large amounts of DGS may mean excessive amounts of nitrogen and phosphorus to dispose of in manure; however, this manure may be a cheaper source of these soil fertility nutrients than commercial sources of fertilizer.

DISTILLERS GRAINS FOR DAIRY CALVES, HEIFERS, AND DRY COWS

Most of the studies with growing cattle are with beef cattle; however, DGS can be used appropriately in diets for dairy calves, heifers, and dry cows. Weight gains were similar among calves fed calf starter containing 0, 28, and 56% of the DM as dried DGS (Thomas et al., 2006a). Rumen papillae development seemed to be optimal with the 28% DGS diet (Thomas et al., 2006b). Distillers grains have also been successfully fed to growing dairy heifers including DGS blended with other feeds (Anderson et al., 2009). Growth rates are optimal when diets are nutritionally balanced, containing appropriate amounts of DGS and other feeds for the age group of animals being considered.

For dry cows, DGS can be fed in appropriate amounts, but likely at about 10% of diet DM. However, Mpapho et al. (2007) successfully fed 15% of the DM as wet DGS throughout the dry period in a long-term feeding experiment.

DISTILLERS GRAINS FOR GRAZING CATTLE

There is little information in the scientific literature about feeding DGS in grazing systems; however, it is safe to assume that it can be done. Nyoka et al. (2009) fed grazing cows 1 of 3 supplemental partial TMR estimated to supply 50% of the cow's daily DMI. Supplements included dried DGS, fish meal, or soybean meal as the protein source. Milk production (31.4 kg/d) was similar for all diets, whereas milk fat (3.61, 3.23, and 3.53% for DGS, fish meal, and soybean meal, respectively) was lower in animals fed fish meal. Concentrations of CLA (1.09 g/100 g of fatty acids) were similar for all diets. When the milk from the 3 dietary protein sources were processed into Cheddar cheese, texture attributes were similar for all cheeses (Nyoka et al., 2007).

In general, when formulating diets to supplement pasture, one would formulate as under other dietary conditions. Although nutritionists may not know accurately the amount and composition of the forages consumed, some estimates have to be made in that regard. For instance, DGS can likely be included up to 20% of the total diet DM if the forages are low in protein; 10% of DM as DGS may be more appropriate in other situations. In many cases, the forages will likely be quite high in protein such that around 15% DGS may meet the protein needs of the cow. Fresh forages are quite wet, typically about 20% DM, and high in RDP. Thus, supplementing with a high RUP source such as DGS may help deliver essential amino acids to the mammary gland of grazing cattle.

OTHER DISTILLERS PRODUCTS

Several distillers products in addition to DGS are already available as livestock feeds and more will be available in the future. For instance, distillers solubles, modified distillers grains, corn bran, corn germ, high-protein distillers grains, and other products that may be higher or lower in fiber and phosphorus than are some current products.

Distillers solubles (about 20% protein, 20% fat, and 1.4% phosphorus on a DM basis) are usually blended with distillers grains before drying to produce DGS, but the solubles may be fed separately. The solubles, which are also referred to as syrup, are usually condensed to 25 to 30% DM before blending with distillers grains or fed as CCDS. Some dairies and feedlots include a small amount of CCDS in diets to decrease dustiness, decrease ingredient separation, decrease animal sorting, and increase palatability. When DaCruz et al. (2005) fed 28% DM CCDS at 0, 5, and 10% of total ration DM to lactating cows, milk production increased 4% with CCDS, although milk fat content was slightly lower and milk protein was unaffected by diets. Sasikala-Appukuttan et al. (2008) fed as much as 20% of the total ration DM as CCDS (4% fat from the CCDS) with no apparent adverse affects on DMI or milk composition. Milk yield tended to be higher for cows fed 10 and 20% CCDS than for cows fed the control (corn-soybean meal–based) diet. However, the authors did not recommend feeding as much as 20% CCDS because diets including that much CCDS contained more than 0.5% phosphorus. High phosphorus can be a concern for dairies under a nutrient management program, in which disposing of excess phosphorus in the manure may be a problem. When Bharathan et al. (2008) fed 10% of DM as CCDS with a small amount of fish oil (0.5% of diet DM), concentrations of *cis*-9, *trans*-11 CLA in the milk fat increased. Whitlock et al. (2002) reported that when cows were fed a small amount of fish oil in combination with a source of linoleic acid (extruded soybeans in that experiment), the CLA concentration in milk fat increased more than when either fish oil or a high linoleic acid fat source were fed separately. In the experiment of Bharathan et al. (2008), using CCDS as the source of linoleic acid with or without fish oil, there was a slight tendency for this same effect. Namely, *cis*-9, *trans*-11 CLA increased 0.59 g/100 g of fatty acids when fed CCDS, CLA increased 0.38 g/100 g of fatty acids over the control when fed fish oil, and CLA increased another 0.62 g/100 g of fatty acids when fed CCDS plus fish oil for a total increase of 1.00 g/100 g of fatty acids, similar to the additive effect (0.97 g/100 g of fatty acids) of the 2 fat sources.

Some ethanol plants offer products called modified distillers grains; however, there are currently no industry guidelines as to what "modified" means. In some cases, the distillers grains are partially dried to approximately 50% DM, sometimes greater or lesser amounts of solubles are added to the distillers grains, or there may be other modifications. These modified corn products can be good feed ingredients to incorporate into dairy cattle diets; however, we are not aware of any refereed articles reporting results with feeding modified distillers grains. A major criticism of modified distillers grains is variation, which indicates that processors are not consistent in the proportion of solubles added to the distillers grains or other processing procedures. It is important that the supplier provide accurate composition analysis data, and that the product be consistent from batch to batch if they expect dairy producers to use the products.

New distillers products that result from fractionation of distillers grains are becoming available. Traditional corn-ethanol production uses a system in which the whole corn kernel is ground, cooked, and fermented. An alternative method can involve the separation of the kernel into its 3 major components, namely bran, germ, and endosperm, before fermentation. Some such products (see Table 1) are becoming more available as feeds for livestock. Processing methods are still being developed, so composition of these products, and of additional products, may vary as processing methods change.

The bran, which can be removed before fermentation, contains similar or lesser amounts of NDF, similar amounts of fat and phosphorus, but less protein and more nonfiber carbohydrate (45%; Janicek et al., 2007; Tedeschi et al., 2009) compared with DGS. When bran was fed to lactating cows at 10, 17.5, or 25% of DM in place of portions of corn silage and alfalfa in diets that were already low in forage (40% of DM as forage in the 10% bran diet), milk yield tended to increase with increasing amounts of bran in the diet and feed efficiency (kg of milk/kg of DMI) increased (Janicek et al., 2007). However, milk fat content tended ($P < 0.06$) to decrease, likely because the diets contained only 15.8 to 9.9% forage NDF even though total NDF in the diets was 31 to 33%.

Corn germ, which can also be removed before fermentation, can provide an alternative fat source to include in dairy cattle diets. The germ from dry grinding of corn contains slightly less than 20% protein and fat (Abdelqader et al., 2009b; Tedeschi et al., 2009), whereas whole corn germ obtained from wet milling contains 44% fat (Montgomery et al., 2005; Miller et al., 2009). The protein in dry-ground corn germ is quite degradable in the rumen (RUP = 28% of CP; Abdelqader et al., 2009a). The fat in the corn germ from wet milling is typically extracted for use as food-grade corn oil and seldom finds use in livestock feeds except when there is a surplus for food usage. Research to date is primarily with feeding corn germ from dry grinding with one recent study that included feeding whole corn germ from wet milling (Miller et al., 2009).

When Abdelqader et al. (2009b) fed the germ from dry grinding at 0, 7, 14, and 21% of ration DM, inclusion at 7 and 14% increased milk and fat yields; however, feeding 21% corn germ decreased the concentration and yield of milk fat and tended to decrease DMI. Thus, at least 14% corn germ can be safely fed to lactating cows but higher amounts may be questionable. However, in their experiment, the problem with feeding as much as 21% corn germ may have not been a problem with the corn germ so much as a problem with total fat in the diet. All diets in that experiment contained 1% additional fat from another source, which caused the 21% corn germ diet to contain more than 8% fat, a situation known to cause problems with ruminal fat digestion and feed intake (NRC, 2001). When Abdelqader et al. (2009c) fed cows diets that were isolipidic at 6% ether extract, feeding 2.5% supplemental lipid as ruminally inert fat (control), 14% corn germ, 30% dried DGS, or 2.5% corn oil, DMI was higher with corn germ (27.2 kg/d) than with the control diet (24.8 kg/d) but similar (26.2 kg/d) for all of the corn fat diets (i.e., corn germ, DGS, and corn oil). Milk production was similar (34.7 kg/d) with all diets. Milk fat concentration was not decreased when feeding corn germ but decreased when feeding corn oil and tended to decrease when feeding DGS. Feeding oils such as corn oil often decreases milk fat concentration, whereas feeding the fat as oilseeds or other forms usually does not cause problems (NRC, 2001). Concentrations of *cis*-9, *trans*-11 CLA were modestly increased by feeding corn germ (Abdelqader et al., 2009b,c) and significantly increased by feeding DGS or corn oil (Abdelqader et al., 2008c). Kelzer et al. (2008) found no differences in total-tract digestibility when feeding corn germ or other corn milling products although ruminal acetate concentrations were decreased.

Higher protein DGS can be produced by removing corn germ, by not adding solubles to distillers grains, or by fat extraction. Two products are currently being evaluating and are starting to be marketed: high-protein dried distillers grains (**HPDDG**) from the corn endosperm, which is approximately 45% CP (Kelzer et al., 2008; Hubbard et al., 2009; Tedeschi et al., 2009), and a low-fat DGS (**dDGS**), produced by solvent extraction of fat for use in biodiesel that is approximately 35% CP (Mjoun et al., 2010). One advantage of HPDDG is that it contains similar concentrations of protein as are present in many other common protein supplements such as soybean meal. However, the high RUP value and low lysine content of HPDDG relative to recommended diet formulations (NRC, 2001) may be considerations in some ration situations. Both of these higher protein DGS products have the advantage of containing more protein than traditional DGS but may be lower in energy content because of containing less fat.

In milk production evaluations of HPDDG, 2 recent studies in Nebraska illustrated that it is a good protein source to include in diets of lactating cows. Hubbard et al. (2009) observed increased milk production when feeding a diet containing 20% HPDDG in place of soy-based protein; milk fat and protein concentrations were not affected by feeding HPDDG. Kelzer et al. (2008) observed similar DMI and milk production when feeding isonitrogenous diets containing HPDDG or regular dried DGS as the protein supplement. In addition, Christen et al. (2009) indicated that feeding HPDDG was as effective as soybean meal, canola meal, and dried DGS as a protein supplement for lactating cows. Like regular DGS, the protein in HPDDG is most limiting in lysine.

Mjoun et al. (2010) concluded that dDGS is also a good feed protein for lactating cows based on an experiment in which cows were fed 0, 10, 20, and 30% of diet DM as dDGS in place of soy-based products. Milk production (34.9 kg/d) was similar for all diets. Likewise, milk composition was not adversely affected by diet, and milk fat concentration actually tended to increase with increasing amounts of dDGS in the diet.

Some higher fiber distillers products are currently being evaluated in beef cattle studies; however, we are not aware of any reports in refereed articles at this time. Although such products may find use in diets for growing heifers and dry cows, they may also be used in diets of lactating cows in situations where producers may feed soyhulls or other high-fiber products.

CONCERNS AND POTENTIAL PROBLEMS WITH DISTILLERS GRAINS

Several items often cited by dairy producers and nutrition consultants may merit mentioning. Inconsistency (variability) of product within and between plants is frequently mentioned. This often occurs with new, startup ethanol plants and is a situation that can be solved by correcting and standardizing processing procedures. Variation in concentrations of fat, protein, and phosphorus makes it difficult to accurately formulate diets, which can be costly to the dairy producer. Variation in fat or phosphorus content of DGS often means that variable amounts of solubles were blended with the distillers grains or that separation occurred in the solubles tank, which may have resulted in more or less of the fat being taken from the solubles tank. These are plant management factors that should be controllable.

High phosphorus or sulfur content in the DGS usually comes via the solubles (Cao et al., 2009). A high phosphorus concentration in DGS usually indicates that more than normal amounts of solubles were blended with the distillers grains. Sulfur-containing compounds are often used for controlling pH and cleaning equipment during various stages in the ethanol plant operation, and these compounds often end up in the solubles. Thus, DGS typically contains more sulfur than is present in the starting grains. Feeding more than 30% DGS that contain higher than normal amounts of sulfur coupled with high-sulfur water or other feeds high in sulfur may result in diets that approach the recommended dietary maximum of 0.4% sulfur in the total ration DM (NRC, 2001).

Difficulty with flowability of dried DGS causing bridging in trucks or rail cars has sometimes been a concern. Apparently, ethanol processors are making a greater effort to minimize such problems by better controlling the drying and temperature of the DGS (Ganesan et al., 2009). Efforts are also being made to pellet DGS, which is not an easy undertaking (Rosentrater, 2007).

Because dairy cows produce a consumable product every day (milk), it is important that they are not fed anything that may ultimately contaminate the milk. Mycotoxins, molds, and other potential contaminants are considered potential problems. Ethanol plants routinely sample and test all loads of grain coming into the plants and reject contaminated loads. This is important because mycotoxins are not destroyed during the ethanol fermentation process or during the production of distillers grains. Thus, contaminated DGS could pose a risk to human health because a metabolite of mycotoxins can transfer to milk (Garcia et al., 2008). Any antibiotics used in ethanol plants are approved products and are ultimately destroyed or inactivated during processing (Shurson et al. 2003). At this time, virginiamycin is the only antibiotic approved for use in ethanol fuel production (US Food and Drug Administration "no objection letter;" November 16, 1993). We are not aware of any situations in which antibiotics used in ethanol production were ever detected in milk from cows fed the resulting DGS.

SUMMARY

The major byproduct (coproduct) of ethanol production, usually made from corn, is DGS, which can be fed to dairy cattle and other livestock as part of the diet. Distillers grains are a good source of protein high in RUP and are a good energy source to include in dairy rations. The intermediate fat concentration and readily digestible fiber contribute to the high energy content in DGS.

Research results on animal performance using DGS were usually similar when fed wet or dried products, although some research results tended to favor the wet products. Diets fed to dairy cattle can contain DGS as replacements for portions of both concentrates and forages, but they usually replace concentrates. Distillers solubles are often blended with distillers grains to provide DGS, but the solubles can also be fed separately as thin stillage or as condensed corn distillers solubles. Nutritionally balanced diets can be formulated that contain 20% or more of the diet dry matter as DGS. There is usually no nutritional advantage of feeding more than 20% DGS because such diets may contain excess protein and phosphorus, although production performance was high even with more than 30% dried DGS in the diet. Milk composition is unchanged at all levels of DGS feeding, but fat content can be decreased if inadequate amounts of effective forage fiber are fed. The fiber in DGS, which often replaces high-starch feeds, does not eliminate acidosis but reduces its risks.

The availability and use of other coproducts of DGS processing, such as condensed corn distillers solubles, corn germ, corn bran, and high-protein distillers grains, will increase in the future. Innovations in processing technology will likely result in additional distillers coproducts from which to choose as livestock feeds.

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