CORN COPRODUCTS FOR CATTLE

***David J. Schingoethe*[1]**
Distinguished Professor
Dairy Science Department
South Dakota State University
Brookings, SD 57007-0647
david_schingoethe@sdstate.edu

ABSTRACT

Corn distillers grains (CDG) and corn gluten feed (CGF) are the major corn coproducts fed to cattle. Both CDG and CGF can be fed wet or dried with animal performance usually similar when fed wet or dried products; however, some research results favored the wet products. Cattle diets can contain CDG or CGF as replacements for portions of both concentrates and forages. Distillers grains is a very good protein (>30% CP) source which is high in ruminally undegradable protein, and is very good energy (NE_L ~2.25 Mcal/kg of DM) source for lactating cows, growing, and finishing cattle. The modest fat concentration (10% of DM) and the readily digestible fiber (39% NDF) contribute to the high energy in CDG. Distillers solubles are often blended with CDG to provide CDG plus solubles, but the solubles can also be fed separately as "thin stillage" or as "condensed corn distillers solubles". Protein and energy values are similar for CDG with or without solubles but the phosphorus content is elevated when solubles are included. The recommended amount of CDG for feeding lactating dairy cows is up to 20% of total ration dry matter; higher amounts - as much as 40 to 50% of ration dry matter - can be successfully fed as an energy source to finishing cattle. Corn gluten feed is a medium protein (24% CP), medium energy (~1.73 Mcal NE_L/kg of DM) feed that also contains an abundance of digestible fiber (35% NDF). While CGF can be fed at higher amounts than one usually feeds CDG, optimal production and feed efficiency of lactating cows occurred with 18 to 27% of ration DM as CGF. Larger amounts, replacing nearly all of the concentrates and forages, were successfully fed to finishing cattle. The fiber in CDG and CGF, which often replaces high starch feeds, does not eliminate acidosis but minimizes its problems. Corn coproducts such as corn gluten meal (65% CP) and other modified products from dry and wet milling plants are additional items available as cattle feeds. Innovations in processing technology will likely result in additional products for future use as livestock feeds.

Introduction

There are several corn coproducts which are potentially important feeds for cattle. Corn distillers grains (CDG) is the major coproduct resulting from dry milling of corn for ethanol production – either for fuel use or human consumption. The resulting distillers solubles may also be fed directly to cattle but are often blended with CDG as CDG with solubles. Additional coproducts may also be available in the future. Quantitatively, dry mill processing of 100 kg of corn produces approximately 40.2L of ethanol, 32.3 kg of CDG with solubles, and 32.3 kg of carbon dioxide.

Corn gluten feed (CGF) is a major coproduct from wet milling of corn in the production of corn oil, corn sweeteners such as dextrose and high fructose corn syrup, starches, and sometimes fermentation of the starches to ethanol. The CGF consists mainly of corn bran and steep liquor. Corn gluten meal is a high protein coproduct that also arises from wet milling while corn germ meal remains after extraction of oil from the corn germ of corn. Quantitatively, one obtains approximately 67.2% corn starch, 19.6% CGF, 5.7% corn gluten meal, and 7.5% corn germ (50% oil) from the wet milling of corn (Long, 1985).

[1] Pages 30-47 *in* Proc. 40th Eastern Nutr. Conf., May 11-12, 2004, Ottawa. ON, Canada

The objective of this presentation is to provide an overview of the use of corn coproducts in diets of both beef and dairy cattle. Major emphasis will be on CDG and CGF.

Nutrient Content of Corn Coproducts

The nutrient content of the major corn coproducts is outlined in Table 1. Specifics related to various products will be discussed later. These tabular values reflect primarily values reported in NRC (1996, 2001) as modified by more recently reported analytical information such as data from Spiehs et al. (2002) for "new generation" CDG. Such products tend to contain more protein, energy, and available phosphorus than CDG from older ethanol plants. All of these corn coproducts contain relatively high amounts of phosphorus, which can be a plus – if additional phosphorus is needed in diets – or a minus – if excess phosphorus in manure needs to be disposed. The composition of CDG is essentially the same with or without solubles added, except for a lower phosphorus content (~0.4%) without solubles because the solubles are quite high (~1.35%) in phosphorus. Therefore, most of the animal performance data reported below use data for CDG or CDG with solubles essentially interchangeably. Protein of CDG is often slightly higher and fat slightly lower without solubles. If a CDG with solubles product contains substantially more fat (e.g > 15%) and/or phosphorus (e.g. >1.0%) than the values listed in Table 1, it is very likely that more than the normal amounts of distillers solubles were blended with the CDG. Both CDG and CGF can be fed wet or dried with similar nutrient contents.

Table 1. Nutrient content of corn coproducts.[1]

	Product			
Item	CDG[2] with solubles	Distillers solubles	CGF[3]	CGM[4]
	(% of DM)			
Crude protein	30.1	18.5	23.8	65.0
RUP[5]% of CP	55.0	30.0	30.0	75.0
$NE_{maintenance}$, Mcal/kg	2.07	2.19	1.87	2.54
NE_{gain}, Mcal/kg	1.41	1.51	1.24	1.79
$NE_{Lactation}$, Mcal/kg	2.26	2.03	1.73	2.38
Neutral detergent fiber (NDF)	41.5	20.0	35.5	11.1
Acid detergent fiber (ADF)	16.1	5.0	12.1	8.2
Ether extract	10.7	21.5	3.5	2.5
Ash	5.2	12.5	6.8	3.3
Calcium	0.22	0.30	0.07	0.06
Phosphorus	0.83	1.35	1.00	0.60
Magnesium	0.33	0.60	0.42	0.14
Potassium	1.10	1.70	1.46	0.46
Sodium	0.30	0.23	0.13	0.05
Sulfur	0.44	0.37	0.44	0.86

[1]Most data are from NRC (1996, 2001), Spiehs et al. (2002), and Birkelo et al. (2004)
[2]CDG = corn distillers grains
[3]CGF = corn gluten feed
[4]CGM = corn gluten feed
[5]RUP = ruminally undegradable protein

Both CDG and CGF contain large amounts of NDF but low amounts of lignin. Thus, these are readily digestible fiber sources, which allows these products to serve as partial replacements for forages as well as for concentrates in diets of dairy and beef cattle. These nonforage fiber sources can supply energy needed for lactation or growth without the ruminal acid load caused by rapidly fermented starchy compounds. In addition, such nonforage fiber sources can partially replace forages at times when forage supplies may be limited. However, because of the small particle size, wet CGF was only 11 to 13% as effective as alfalfa hay in maintaining ruminal pH and rumination activity but 74% as effective as alfalfa silage in maintaining milk fat percentages (Allan and Grant, 2000).

Corn Distillers Grains

Corn distillers grains is a good source of ruminally undegradable protein (RUP). The reported values of 55% of CP as RUP is probably an appropriate figure to use in most cases. Most reported values range from 47% to 57% RUP. One often assumes that wet CDG has lower concentrations of RUP than does dried CDG, but the differences are slight. Firkins et al. (1984) reported 47% RUP for wet CDG and 54% RUP for the dried product, which probably represents a realistic difference in RUP for the wet versus the dried products. Most of the readily degradable proteins in corn have been degraded during the fermentation process, so the protein remaining in the CDG is going to be proportionately higher in RUP than in the original corn. However, if RUP values for dried CDG are quite high (e.g. > 80% of CP), it may be advisable to check for heat damaged, undigestible protein.

The quality of protein in CDG is fairly good. As with most corn products, lysine is the first limiting amino acid in CDG for lactating cows. Therefore, sometimes (Nichols et al., 1998) but not always (Liu et al., 2000) milk production increased when fed supplemental ruminally protected lysine and methionine, or when the CDG was blended with other protein supplements that contained more lysine.

Table 2 summarizes milk production from several experiments in which cows were fed CDG. In experiments that compared CDG to soybean meal as the protein supplement, production was similar when fed wet (Schingoethe et al. 1983; 1999) or dried CDG (Clark and Armentano, 1993; Owen and Larson, 1991), or was higher (Powers et al., 1995; Nichols et al., 1998) when fed dried CDG. Production responses to CDG were similar with or without solubles added. Florida research (Powers et al., 1995) indicated higher production when fed CDG plus solubles from whiskey or from fuel ethanol plants, than when fed soybean meal. When CDG products were darker and possibly heat damaged, milk production was lower than when fed lighter, golden colored CDG (Powers et al., 1995). This indicates the importance of product quality and many ethanol plants are striving to consistently produce improved quality CDG products. Such products are currently being evaluated (Schingoethe, 2004, unpublished results).

Table 2. Milk production response to diets containing corn distillers grains as the supplemental protein source.

	Protein supplement					
Experiment	SBM	SBM RPLM	CDG	CDG +RPLM[1]	BLEND	BLEND +RPLM
Schingoethe et al., 1983	27.0	---	27.6[3]	---	---	---
Owen & Larson, 1991	33.8	---	34.3[5]	---	---	---
Clark & Armentano, 1993	32.3	---	32.5	---	---	---
Powers et al., 1995	26.8	---	23.7[6]	---	---	---
Powers et al., 1995	26.8	---	27.8[7]	---	---	---
Powers et al., 1995	26.8	---	26.9[8]	---	---	---
Nichols et al., 1998	34.3	34.0	35.3[4]	36.7	---	---
Schingoethe et al., 1999	30.7	---	30.8[3]	---	---	---
Liu et al., 2000	---	---	32.6[4]	31.7	32.8	32.8

[1]RPLM: ruminally protected lysine and methionine
[2]BLEND: supplemental protein was approximately 25% from CDG, 25% from fish meal, and 50% from soybean meal (SBM)
[3]Wet CDG
[4]Dried CDG
[5]Dried CDG plus solubles
[6]Whiskey dried CDG plus solubles
[7]Fuel-ethanol dried CDG plus solubles
[8]Darker fuel-ethanol dried CDG plus solubles

The CDG available in recent years also contains more energy than older "book" values. Recent research (Birkelo et al., 2004) indicated that wet CDG contains approximately 2.25 Mcal/kg of $NE_{Lactation}$, 10 to 15% more energy than published older references and even more than in the recent dairy NRC (2001) for CDG with solubles. This likely reflects a higher energy value for newer generation distillers grains and does not necessarily reflect higher energy in wet than in dried CDG; that is a separate comparison that has not been made

Wet versus dried CDG. So far the presentation has contained information almost interchangeably about both wet and dried distillers grains, because the nutrient content of the dry matter is essentially the same for both wet and dried CDG, except for possibly slightly lower RUP values for wet than for dried CDG (Firkins et al., 1984). A trial (Al-Suwaiegh et al. (2002) with lactating cows directly compared wet versus dried CDG and reported similar production for both wet and dried CDG. Additional research comparing wet versus dried CDG is in progress (Schingoethe, unpublished results). Data comparing wet versus dried CDG with growing and finishing beef cattle (Ham et al., 1994) indicated similar animal performance when fed wet or dried CDG.

The main consideration regarding the use of wet versus dried CDG are handling and costs. Dried products can be stored for extended periods of time, can be shipped greater distances more economically and conveniently than wet CDG, and can be easily blended with other dietary ingredients. However, feeding wet CDG avoids the costs of drying the product. But, there are several factors to consider when feeding wet CDG that are not concerns when feeding CDG with solubles. First, the product will not remain fresh and palatable for extended periods of time; 5 to 7 days is the norm. This storage time span will vary somewhat with environmental temperature as products will spoil and become unpalatable more rapidly in hot weather, but may be kept in an acceptable form as long as three weeks under cool conditions. Surface molds occasionally occur thus, there is usually some feed lost; a problem that wouldn't be a consideration with dried CDG, or CDG with solubles. The addition of preservatives such as propionic acid or other organic acids may extend the shelf life of wet CDG, but scientific journal publications that document such results are difficult to find. In recent research, we at SDSU (Kalscheur et al., 2002; 2003; 2004) successfully stored wet CDG for more than six months in silo bags. The wet CDG was stored alone or blended with soyhulls (Kalscheur et al., 2002) or with corn silage (Kalscheur et al., 2003). Some field reports indicate successful preservation of wet distillers grains for more than a year in silo bags.

How much CDG can be fed? I recommend that dairy producers feed up to a maximum of about 20% of ration DM as distillers grains. With typical feed intakes of lactating cows, this would be about 4.5 to 5.5 kg of dried CDG or 15 to 17 kg of wet CDG per cow daily. There are usually no palatability problems and one can usually formulate nutritionally balanced diets with up to that level of distillers grains in the diet. For instance, with diets containing 25% of the dry matter as corn silage, 25% as alfalfa hay, and 50% concentrate mix, the CDG can likely 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. In diets that contain higher proportions of corn silage, even greater amounts of CDG may be useable. However, the need for some other protein supplement, protein quality (e.g. lysine limitation), and phosphorus concentration may become factors to consider. In diets containing higher proportions of alfalfa, less CDG may be needed to supply the protein required in the diet, and in fact the diet may not be able to utilize as much CDG. When feeding more than 20% distillers grains, one is likely to feed excess protein, unless forages are all or mostly corn silage and/or grass hay.

Grings et al. (1992) observed similar DM intake and milk production when cows were fed as much as 31.6% of ration DM as dried CDG with solubles. In previous research (Schingoethe et al., 1999), we fed slightly more than 30% of the ration DM as wet CDG with decreased DM intake but no decrease in milk production. However, recent research by our group (Hippen et al., 2003; 2004) in which as much as 40% of ration dry matter was fed as CDG indicated problems when the CDG provided more than 20 to 25% of the ration DM. With wet CDG (Hippen et al., 2003), DM intake decreased when diets contained more than 20% wet CDG with a corresponding decrease in milk production. Gut fill may have limited DM intake of these wet diets because total DM intake may decrease when the diet is less than 50% DM, especially when fermented feeds are included in the diet (NRC, 2001). However, when dried CDG with solubles was fed, (Hippen et al., 2004) DM intake and milk production still decreased when diets contained 27 to 40% dried CDG. Milk fat percentages also decreased when fed more than 13% CDG. Some field reports indicated milk fat depression when diets contained more than 10% of ration DM as wet CDG (Hutjens, 2004); however, those observations are not supported by research results. We don't know why that occurred because milk fat percentages were not adversely affected by distillers grains in previous research (e.g. see Table 2) in which 20 to 30% CDG were fed. In cases of milk fat depression, one may need to look at the amount of forage fiber in the diet because the amounts may be inadequate.

Beef cattle have been successfully fed as much as 40% of ration DM as wet or dried CDG with solubles (Al-Suwaiegh et al., 2002; Ham et al., 1994; Larson et al., 1993). Such diets were fed primarily as energy sources but, admittedly, contained more protein and phosphorus than finishing cattle needed. These experiments suggested that wet CDG contained 29 to 40% more NE_{gain} than dry-rolled corn, but dried CDG contained only 21% more NE_{gain} than dry-rolled corn (Ham et al., 1994). Increased feed efficiency when fed distillers grains products in place of corn may in part be due to fewer off-feed problems and reduced subacute acidosis (Ham et al., 1994; Larson et al., 1993). Similar results were observed when feeding wet CGF (Krehbiel et al., 1995). That is because, even though the distillers grains contains similar amounts or more energy than corn, the energy in distillers grains is primarily in the form of digestible fiber and fat; in corn most of the energy is as starch. Ruminal starch fermentation is more likely to result in acidosis, laminitis, and fatty liver.

Corn Distillers Solubles

Distillers solubles are usually blended with the distillers grains before drying to produce CDG with solubles, but the solubles may be fed separately also. We (DaCruz et al., 1996) conducted an experiment with lactating cows in which condensed corn distillers solubles (CCDS) were fed at 0, 5, and 10% of total ration DM. The CCDS contained 28% DM and that dry matter contained 18% CP, 21.5% ether extract (fat), 12.5% minerals, and approximately 2.01 Mcal NE_L/kg. Milk production (34.1, 35.5 and 35.8 kg/d for 0, 5, and 10% CCDS diets) increased when fed the CCDS. Milk fat percentages (3.54, 3.33, and 3.43) were slightly lower ($P < 0.05$) when fed CCDS while milk protein percentages (2.93, 2.97, 2.95) were unaffected by diets. The added energy from fat in the CCDS likely contributed to the increased milk production but may have also caused the observed slight milk fat depression. Dry matter intakes (24.8, 24.4, and 22.5 kg/d) were similar for control and CCDS diets, although intake tended ($P < 0.10$) to be lower when fed 10% rather than 5% CCDS. It was concluded that feeding CCDS at 5% of ration DM is effective and profitable for dairy producers. There was no additional advantage to feeding CCDS at 10% of ration DM. Condensed and thin distillers solubles have also been successfully used as protein and energy sources in beef cattle diets (see Ham et al., 1994).

Corn Gluten Feed

Corn gluten feed, often fed as wet CGF, is a relatively high fiber, medium-energy, medium-crude protein product that can be fed to dairy and beef cattle. The energy value of wet CGF is 92 to 100% of the energy value of shelled corn (Firkins et al., 1985; Ham et al., 1995); values were slightly lower for dry CGF. Schrage et al. (1991) determined the $NE_{maintenance}$ and NE_{gain} of wet CGF to be 1.60 and 1.32 Mcal/kg of DM, respectively.

Cattle can be fed very large amounts of wet CGF with very acceptable animal performance. Sindt et al. (2003) obtained the highest weight gains and feed efficiencies when diets fed to finishing steers contained 30% wet CGF rather than 0 or 60% wet CGF. This amount (30% of DM) was similar to the 27% of DM as wet CGF that Bernard et al. (1991) indicated could be fed to lactating cows without altering milk yields. A summary of beef feedlot research (Stock et al., 1999) indicated that the efficiency of gain was improved by 5.1% when diets containing 25 to 50% wet CGF were compared to dry-rolled corn. Restricted feeding of growing cattle may furtherimprove the utilization of wet CGF and allow greater dietary inclusions of wet CGF (Hussein and Berger, 1995; Montgomery et al., 2003).

Lactating cows can also consume quite large amounts of CGF with acceptable performance, but the response was more variable in earlier studies (see Van Baale et al., 2001). Staples et al. (1984) reported linear declines in DM intake and milk yield as amounts of wet CGF increased from at 0 to 40% of DM in 50% corn silage diets. Dry matter content of the total diet may have been part of the problem as mentioned earlier regarding the feeding of wet CDG. However, Armentano and Dentine (1988) observed no reductions in DM intake and milk yield when diets contained as much as 7.9 kg/d (~36% of ration DM) as wet CGF. The wet CGF replaced only concentrates in most of the above studies. When wet CGF replaced up to 35% of ration DM as a mix of alfalfa hay, corn silage, and corn grain, milk production was greater than when fed the control diet (Van Baale et al., 2001). In experiments that included as much as 45% of ration DM as wet CGF, Schroeder (2003) concluded that 18.6% of dietary DM as wet CGF in place of portions of both forage and concentrate would maximize milk yield without negatively affecting milk composition or feed efficiency.

Data from Boddugari et al. (2001) indicated that a new wet corn milling product (CMP) can effectively replace all of the concentrate and up to 45% of the forage in the diet of lactating cows. The CMP, which is similar to wet CGF, was composed of corn bran, fermented corn extractives, corn germ meal, and additional sources of ruminally undegradable protein to increase the metabolizable protein content of the product. This wet CMP contained (DM basis): 23.1% crude protein, 9.9% RUP, 40.3% NDF,13.7% ADF, and 2.6% ether extract. A modified corn fiber (MCF) produced by a secondary, bacterial and yeast-driven fermentation for the corn bran may enable corn processors to more fully recover ethanol from corn (Peter et al., 2000). However, feeding MCF (23.9% CP, 49.4% NDF, 45.4% ADF) resulted in poorer performance of heifers, suggesting a limited feeding value because of the high acid detergent insoluble nitrogen content and slow protein digestion.

Corn Gluten Meal

Corn gluten meal (CGM) is a high protein (65% CP) high RUP (75% of CP) feed that is a very good protein supplement. However, it is best to blend CGM with other protein supplements for optimal animal performance. Because of its high RUP level and lysine limitation, feeding CGM as the only protein supplement did not support the same amount of milk production as soybean meal-containing diets in a series of multi-university studies, even when the CGM diets were supplemented with ruminally protected lysine and methionine (Polan et al., 1991). A blend of several high quality proteins (blood meal, CGM, canola meal, and fish meal) as in the study by Piepenbrink et al. (1998) supported similar milk production than was supported by soybean meal-containing diets.

The Future?

We don't know what corn coproducts will be available to the feed industry in the future. However, if we can speculate, I would not be surprised to see improved products and new products available. For instance, improvements in fermentation technology already provide CDG today that contains more protein and energy than CDG of previous years contained. It also may be feasible to "fractionate" in some manner CDG and/or CGF into products that are higher in protein, other products that are higher in fat or in fiber, and products that are higher or lower in phosphorus. I base these comments on prior research experience with feeding whey, the coproduct from cheese manufacturing. At one time a person had a choice between "whole whey" or "whole whey", either liquid or dried. Today, a large number of whey products from protein concentrates to lactose are available to the human food and animal feed industries. A similar situation could also occur with corn coproducts.

References

Allan, D. M., and R. J. Grant. 2000. Interactions between forage and wet corn gluten feed as sources of fiber in diets of lactating dairy cows. J. Dairy Sci. 83:322-331.

Al-Suwaiegh, S., K. C. Fanning, R. J. Grant, C. T. Milton, and T. J. Klopfenstein. 2002. Utilization of distillers grains from the fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle. J. Anim. Sci. 80:1105-1111.

Armentano, L. E., M. R. Dentine. 1988. Wet corn gluten feed as a supplement for lactating dairy cattle and growing heifers. J. Dairy Sci. 71:990-995.

Bernard, J. K., R. C. Delost, F. J. Mueller, J. K. Miller, and W. M. Miller. 1991. Effect of wet or dry corn gluten feed on nutrient digestibility and milk yield and composition. J. Dairy Sci. 74:3913-3949.

Birkelo, C. P., M. J. Brouk, and D. J. Schingoethe. 2004. The energy content of wet corn distillers grains for lactating dairy cows. J. Dairy Sci. 87:(in press).

Boddugari, K., R. J. Grant, R. Stock, and M. Lewis. 2001. Maximal replacement of forage and concentrate with a new wet corn milling product for lactating dairy cows. J. Dairy Sci. 84:873-884.

Clark, P. W., and L. E. Armentano. 1993. Effectiveness of neutral detergent fiber in whole cottonseed and dried distillers grains compared with alfalfa haylage. J. Dairy Sci. 76:2644-2650.

DaCruz, C. R., M. J. Brouk, and D. J. Schingoethe. 1996. Utilization of condensed corn distillers solubles in lactating dairy cow diets. Pages 95-97 in Proc. 1996 SD Dairy/Forage Conf., Brookings, SD.

Firkins, J. L., L. L. Berger, and G. C. Fahey, Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60:847-860.

Firkins, J. L., L. L. Berger, G. C. Fahey, Jr., and N. R. Merchen. 1984. Ruminal nitrogen degradability and escape of wet and dry distillers grains and wet and dry corn gluten feed. J. Dairy Sci. 67:1936-1944.

Grings, E. E., R. E. Roffler, and D. P. Deitelhoff. 1992. Response of dairy cows to additions of distillers dried grains with solubles in alfalfa-based diets. J. Dairy Sci. 75:1946-1953.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, and R. P. Huffman. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. J. Anim. Sci. 73:353-359.

Ham, G. A., R. A. Stock, T. .J. Klopfenstein, E. M .Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Hippen, A. R., K. F. Kalscheur, D. J. Schingoethe, and A. D. Garcia. 2004. Increasing inclusion of dried corn distillers grains in dairy cow diets. J. Dairy Sci. 87: (Abstr.)

Hippen, A. R., K. N. Linke, K. F. Kalscheur, D. J. Schingoethe, and A. D. Garcia. 2003. Increased concentration of wet corn distillers grains in dairy cow diets. J. Dairy Sci. 86(Suppl. 1):340 (Abstr.)

Hussein, H. S., and L. L. Berger. 1995. Effects of feed intake and dietary level of wet corn gluten feed on feedlot performance, digestibility of nutrients, and carcass characteristics of growing-finishing beef heifers. J. Anim. Sci. 78:3246-3252.

Hutjens, M. F. 2004. Questions about wet distillers'. Hoard's Dairyman 149:261.

Kalscheur, K. F., A. D. Garcia, A. R. Hippen, and D. J. Schingoethe. 2004. Growth of dairy heifers fed wet corn distillers grains ensiled with other feeds. J. Dairy Sci. 87: (Abstr.)

Kalscheur, K. F., A. D. Garcia, A. R. Hippen, and D. J. Schingoethe. 2003. Fermentation characteristics of ensiling wet corn distillers grains in combination with corn silage. J. Dairy Sci. 86(Suppl. 1):211 (Abstr.)

Kalscheur, K. F., A. D. Garcia, A. R. Hippen, and D. J. Schingoethe. 2002. Ensiling wet corn distillers grains alone or in combination with soyhulls. J. Dairy Sci. 85(Suppl. 1):234 (Abstr.)

Krehbiel, C. R., R. A. Stock, D. W. Herold, D. H . Shain, G. A. Ham, and J. E. Carulla. 1995. Feeding wet corn gluten feed to reduce subacute acidosis in cattle. J. Anim. Sci. 73:2931-2939.

Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, and R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. J. Anim. Sci. 71:2228-2236.

Liu, C., D. J. Schingoethe, and G. A. Stegeman. 2000. Corn distillers grains versus a blend of protein supplements with or without ruminally protected amino acids for lactating cows. J. Dairy Sci. 83:2075-2084.

Long, J. E. 1985. The wet milling process: products and coproducts. Corn Gluten Conf. for Livestock, Ames, IA.

Montgomery, S. P., J. S. Drouillard, J. J. Sindt, T. B. Farran, J. N. Pike, A. M. Trater, C. M. Coetzer, H. J. La Brune, R. D. Hunter, and R. A. Stock. 2003. Combinations of alfalfa hay and wet corn gluten feed in limit-fed growing diets for beef cattle. J. Anim. Sci. 81:1671-1680.

National Research Council. 1996. Nutrient Requirements for Beef Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

National Research Council. 2001. Nutrient Requirements for Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

Nichols, J. R., D. J. Schingoethe, H. A. Maiga, M. J. Brouk, and M. S. Piepenbrink. 1998. Evaluation of corn distillers grains and ruminally protected lysine and methionine for lactating dairy cows. J. Dairy Sci. 81:482-491.

Owen, F. G., and L. L. Larson. 1991. Corn distillers dried grains versus soybean meal in lactation diets. J. Dairy Sci. 74:972-979.

Peter, C. M., D. B. Faulkner, N. R. Merchen, D. F. Parrett, T. G. Nash, and J. M. Dahlquist. 2000. The effects of corn milling coproducts on growth performance and diet digestibility by beef cattle. J. Anim. Sci. 78:1-6.

Piepenbrink, M. S., D. J. Schingoethe, M. J. Brouk, and G. A. Stegeman. 1998. Systems to evaluate the protein quality of diets fed to lactating cows. J. Dairy Sci. 81:1046-1061.

Polan, C. E., K. A. Cummins, C. J. Sniffen, T. V. Muscato, J. L. Vincini, B. A. Crooker, J. H. Clark, D. G. Johnson, D. E. Otterby, B. Guillaume, L. D. Muller, G. A. Varga, R. A. Murray, and S. B. Pierce-Sandner. 1991. Responses of dairy cows to supplemental rumen-protected forms of methionine and lysine. J. Dairy Sci. 74:2997-3013.

Powers, W. J., H. H. Van Horn, B. Harris, Jr., and C. J Wilcox. 1995. Effects of variable sources of distillers dried grains plus solubles or milk yield and composition. J. Dairy Sci. 78:388-396.

Schingoethe. D. J., M. J. Brouk, and C. P. Birkelo. 1999. Milk production and composition from cows fed wet corn distillers grains. J. Dairy Sci. 82:574-580.

Schingoethe, D. J., A. K. Clark, and H. H. Voelker. 1983. Wet corn distillers grains in lactating dairy cow rations. J. Dairy Sci. 66:345-349.

Schrage, M. P., H. D. Woody, and A. W. Young. 1991. Net energy of ensiled wet corn gluten feed in corn silage diets for finishing steers. J. Anim. Sci. 69:2204-2210.

Schroeder, J. W. 2003. Optimizing the level of wet corn gluten feed in the diet of lactating dairy cows. J. Dairy Sci. 86:844-851.

Sindt, J. J., J. S. Drouillard, H. Thippareddi, R. K. Phebus, D. L. Lambert, S. P. Montgomery, T. B. Farran, H. J. La Brune, J. J. Higgins, and R. T. Ethington. 2002. Evaluation of finishing performance, carcass characteristics, acid-resistant E. coli and total coliforms from steers fed combinations of wet corn gluten feed and steam-flaked corn. J. Anim. Sci. 80:3328-3335.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient data base for distillers dried grains with solubles produced from new generation ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Staples, C. R., C. L. Davis, G. C. McCoy, and J. H. Clark. 1984. Feeding value of wet corn gluten feed for lactating dairy cows. J. Dairy Sci. 67:1214-1220.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 1999. Review of new information in the use of wet and dry milling food byproducts in feedlot diets. J. Anim. Sci. 77(Suppl. 1):247 (Abstr.).

Van Baale, M. J., J. E. Shirley, E. C. Titgemeyer, A. F. Park, M. J. Meyer, R. U. Lundquist, and R. T. Ethington. 2001. Evaluation of wet corn gluten feed in diets for lactating dairy cows. J. Dairy Sci. 84:2478-2485.