Lactational Responses to Corn Distillers Grains: A *Meta*-Analysis with Focus on Diet Fermentability and Protein Quality

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Take Home Message

- As a general rule-of-thumb, recommending a specific concentration of corn distillers grains **(CDG)** in lactation rations is too simple and may result in less than expected lactation performance.
- Nutritional factors such as the overall diet fermentability (e.g., corn silage vs. alfalfa silage; high moisture vs. dry corn; starch concentration) of different rations and/or their protein quality influence markedly lactational responses when CDG replaces other energy and protein ingredients in rations.
- In our analysis, milk fat concentration response was not related to dietary CDG over the entire database. However, the response was related to the milk fat concentration of cows fed a similar control diet without CDG. Milk fat concentration greater than 3.6% for cows fed control diets related to a negative milk fat concentration response when CDG was added, regardless of dietary concentration of CDG. However, at milk fat concentrations of less than 3.6% for control cows, milk fat concentration response to CDG was slightly positive.
- Milk yield response related to increasing concentrations of CDG in diets. It peaked at 1.2 kg/cow per d with 21% CDG. However, factors associated with differing diet fermentability were associated with variable responses. Greatest milk yield response to CDG was with 24% corn silage or 23% starch and concentrations greater than 47% corn silage or 32% starch resulted in negative milk responses to CDG. Milk yield responses also differed by level of milk production and were often more evident in higher- (> 30.0 kg MY/d) compared with lower-producing cows.
- When formulating diets with CDG, diet fermentability and level of milk production must be considered. Concentrations of corn silage and starch must be moderate to optimize lactational responses to CDG. Overall, lactational response to CDG in our analysis was dependent on diet fermentability and milk fat concentration of cows fed the control diet.
- Milk yield and milk true protein yield responses to added CDG were maximized when approximately 8.5% of the total dietary crude protein was non-corn crude protein. Milk yield response peaked for higher-producing cows (> 30.0 kg MY/cow per d) at 4.3% dietary corn-based crude protein, but declined linearly for lower-producing cows (< 30.0 kg/cow per d) as corn-based dietary crude protein increased.
- Milk true protein yield response declined as corn-based dietary crude protein concentration increased but milk true protein concentration response was not affected when diets with CDG had more than 6.5% dietary non-corn crude protein. Overall, 8.5% dietary non-corn-based crude

protein was necessary in lactation diets to maximize lactational responses from diets containing CDG. The necessity of supplementing dietary non-corn crude protein to maximize milk and milk protein yields limits the amount of dietary corn-based crude protein, including that from CDG, that can be included in rations.

- Our analysis indicates that at the very least 5% of total dietary DM as CP should be from sources other than corn-based ingredients to maintain yields of milk and protein from diets with CDG, and that about 8.5% CP from non-corn sources maximized yields. This limits the amount of CDG that can be fed effectively without over-feeding protein and increasing N excretion.
- Ration fermentability and protein quality must be taken into account in routine ration formulation if optimal nutrition programs and profit margins are goals.

Introduction

Minimal references are included for this proceedings paper. Complete citation of contributions and ideas of many other authors are provided in Hollmann et al. (2011a,b). All numeric values of dietary nutrients and ingredients are listed on a dry basis.

Recent increase in supply of corn distillers grains (CDG) raises questions about the extent to which they can be used most effectively in rations of lactating dairy cows. In Michigan, dairy farmers and nutritionists ask how much CDG can be used effectively. We often hear that more than 5 to 10% CDG reduces milk yield (MY) and milk fat concentration and yield. In contrast, a recent comprehensive summary suggested that as much as 20 to 30% distillers grains can be used without detrimental effects on MY or composition if diets contain at least 50% forage; however, greater than 30% distillers grains reduced feed intake and MY (Schingoethe et al., 2009).

Is it possible that several particular factors or characteristics of rations and/or cows, not yet fully elucidated, influence lactational responses actually observed in many dairy farms when dietary concentrations of CDG exceed 5 to 10%?

To address this question we aimed to evaluate the effects of fermentability of the diet, level of milk production of the cows, and dietary protein quality and quantity as they might influence and interact to affect lactational responses when CDG are included in rations.

Ration Fermentability

A main concern in Michigan when CDG are in rations is potential reduction from normal milk fat tests and milk fat yields (milk fat depression = MFD). Typically, MFD results from interaction of several dietary risk factors such as concentration of unsaturated fatty acids (FA), fiber and grain fermentability, and type and particle length of forage (Lock, 2010). These factors (or a combination) can alter ruminal metabolism yielding more of unique FA (e.g., *trans*-10 *cis*-12 $C_{18:2}$) that reduce milk fat yield (Bauman and Griinari, 2003). Corn distillers grains may accentuate these changes because they (and other corn-based ingredients such as corn grain and corn silage) contain high amounts of unsaturated FA (Lock, 2010). Also, NDF in CDG is highly digestible and does not stimulate chewing and rumination very well (Clark and Armentano, 1997). Consequently, CDG may increase risk of MFD, especially in highly fermentable diets.

Level of Milk Production Effect

Also, MFD was found when highly fermentable diets were fed to lower-, but not higher-producing cows (Bradford and Allen, 2004). This related to concentration of *trans*-10 $C_{18:1}$ FA in milk fat, an indicator of MFD. Lower-producing cows have slower rates of digesta passage from the rumen and less absorption of VFA than higher-producing cows. Additionally, lower and less stable ruminal pH was measured in lower- compared with higher-producing cows (Voelker and Allen, 2003). It was suggested that lower ruminal pH of lower-producing cows fed a highly fermentable diet modified ruminal biohydrogenation pathways leading to MFD at the lower milk production level. Thus, level of milk production, as a factor, might be an important when evaluating effects of CDG on lactational performance and optimal strategies for ration formulation.

Protein Quality and Quantity

Additionally, some factors associated with diet fermentability are inherently related in rations with other characteristics of corn-based ingredients. For example, corn-based ingredients are relatively poor in protein quality, unable to meet essential amino acids requirements of lactating cows. Thus, some lactational responses to CDG may result from interrelated aspects of diet fermentability, and protein quality and quantity. Corn-based ingredients including CDG supply less lysine [e.g., 3.0% of total crude protein (CP); NRC, 2001; Schingoethe et al., 2009] compared with, for example, soybean meal (6.3% lysine) (NRC, 2001). Thus, diets with abundant corn-based ingredients can be deficient, if rations are balanced for CP and not for essential amino acids. Therefore, partial substitution of CDG for non-corn-based protein feed ingredients often reduces dietary lysine. This deficiency reduces milk true protein yield and concentration, and, to a lesser extent milk yield (NRC, 2001).

Our Objective

Therefore, our objective was to evaluate by *meta*-analysis lactational responses of dairy cows to rations with and without CDG focusing on potential effects of: 1) ration fermentability; 2) level of milk production; and, 3) quality and quantity of dietary protein (inclusion of non-corn versus corn-based feed ingredients). We aimed to better understand some of the field observations (such as reduced milk yield, and fat yield and concentrations) when CDG are included sometimes (but not always) in lactation rations in Michigan dairy farms.

Database and Analysis

The peer-reviewed literature was screened for feeding trials reporting lactation responses and the specific dietary characteristics of interest. To be included data had to meet certain criteria. All distillers grains in treatment diets (CDG-containing diets) originated from corn grain. Forage sources in diets were limited to corn silage, alfalfa hay, and/or haylage, and grain source was limited to greater than 80% corn (vs. small grains). Therefore, diets from selected trials were similar to typical Midwestern U.S. dairy cow rations. The final database included 44 treatment means from 18 trials in 16 peer-reviewed publications. More details about database development, description of diets and variables, and statistical methods of the *meta*-analysis are in Hollmann et al. (2011a,b).

Descriptors of Diets and Response Variables

Independent variables were: dietary concentrations of DM, CDG, forage, corn silage, grain (including dry corn, high moisture corn, barley, and hominy), NDF, NDF from forage, and ether extract (EE) of the CONTROL (non-CDG-containing diet within trial) and CDG diets. If dietary FA concentration was reported, EE was computed using the equation: [EE] = [FA] + 1. Starch concentrations were calculated from dietary ingredient composition and book values (NRC, 2001); CDG was assumed to contain no starch. Forage NDF was only calculated for trials reporting NDF analysis of forages. Difference (**Δ**) in concentration of each individual nutrient was calculated by subtraction of the nutrient concentration in CONTROL diet minus the CDG diet (Tables 1 and 3).

Table 1. Descriptive information of fermentability in CONTROL diets (Ctrl), corn distillers grains (CDG) diets, and the changes in CONTROL and CDG diets (Δ; CDG minus Ctrl) in trials included in the statistical analyses of CDG on lactational performance.

Variable	Diet	N	Mean	SD	Min	Max
DM, %		26	59.4	9.49	39.4	72.5
			g/100 g DM			
Corn distillers grains	CDG	44	17.4	8.40	4.2	41.6
Corn silage	Ctrl	44	35.4	15.13	0.0	56.0
	CDG	44	34.9	15.47	0.0	56.0
	Δ[a]	44	-0.54	1.693	-6.2	1.41
Starch[b]	Ctrl	44	33.2	5.59	22.0	43.3
	CDG	44	27.8	5.77	16.8	39.3
	Δ	44	-5.37	3.707	-15.3	1.9
Grain	Ctrl	44	30.4	7.85	16.3	48.0
	CDG	44	22.7	8.80	5.9	38.4
	Δ	44	-7.74	5.320	-21.8	2.7
Forage	Ctrl	44	48.8	6.36	29.6	57.9
	CDG	44	48.1	7.41	29.6	57.8
	Δ	44	-0.73	2.38	-9.3	2.1
Neutral-detergent fiber	Ctrl	35	30.2	3.86	19.7	35.7
	CDG	35	34.8	5.23	23.5	42.9
	Δ	35	4.65	3.28	0.1	14.6
Forage-NDF	CDG	23	20.4	4.69	12.0	27.9
Ether extract[c]	Ctrl	32	4.1	1.10	2.2	6.0
	CDG	32	5.2	0.80	3.7	6.5
	Δ	32	1.05	0.83	-0.3	2.9

[a] Change in response of dependent variable to dietary inclusion of CDG. Positive value represents an increase in response to CDG and a negative value a decrease in response.
[b] Calculated from book values (NRC, 2001).
[c] Conversion of dietary fat content: ether extract [%] = dietary fat [%] + 1.

Dietary concentrations of CDG across all trials in the final database ranged from 4.2 to 42.0% and averaged 17.0 ± 8.40% (mean ± standard deviation). Average dietary concentrations of especially relevant ingredients and nutrients among diets containing CDG were: 49 ± 6.4% forage (mean ± standard deviation); 36 ± 15.5% corn silage; 23 ± 8.8% corn grain; 28 ± 5.8% starch; and, 16.8 ± 1.91% CP (Table 1). For evaluation, diet fermentability was classified by dietary concentrations of corn silage, starch, corn grain, and different physical forms of corn grain (high moisture corn vs. dry corn). In all cases, CDG replaced solely or predominantly concentrate feedstuffs of the CONTROL diet within trial, although this was not a criterion to be in the database.

Lactation responses to the CDG diet compared with CONTROL [no (0%) CDG] were calculated by difference within trial for variables of interest. Dependent response variables included: milk yield (MY), 4%-fat-corrected milk yield (FCMY), milk fat concentration and yield, and dry matter intake (DMI). If FCMY was not reported, it was calculated as: MY x [0.4 + 15 x milk fat (%) /100]. Lactational performance of cows fed CONTROL or CDG diets and the corresponding response to CDG are in Table 2.

Table 2. Descriptive information about lactational performance in CONTROL diets (Ctrl) and corn distillers grains (CDG) diets, and the resulting responses to CDG inclusion (Δ; CDG minus Ctrl) in trials included in the *meta*-analysis (n = 44).

Variable	Diet	Mean	SD	Min	Max
DM intake, kg/cow per d	Ctrl	23.1	2.12	19.4	29.4
	CDG	23.1	2.56	17.6	31.7
	Δ[a]	0.02	1.194	-2.6	2.6
Milk yield, kg/cow per d	Ctrl	31.6	5.83	24.3	44.6
	CDG	32.0	6.49	23.3	46.4
	Δ	0.45	2.099	-5.7	3.8
4%-fat-corrected milk yield[b], kg/cow per d	Ctrl	28.7	5.06	21.6	40.5
	CDG	29.2	5.68	20.6	41.7
	Δ	0.60	1.858	-3.6	4.4
Milk fat, %	Ctrl	3.42	0.245	2.75	3.90
	CDG	3.47	0.229	2.87	3.85
	Δ	0.049	0.1780	-0.21	0.46
Milk fat yield, g/cow per d	Ctrl	1,074	182	860	1,490
	CDG	1,100	200	830	1,530
	Δ	26	77.6	-200	160
Milk true protein, %	Ctrl	3.03	0.116	2.75	3.28
	CDG	2.96	0.150	2.57	3.19
	Δ[c]	-0.067	0.1199	-0.42	0.18
Milk true protein yield, g/cow per d	Ctrl	952	171	762	1,360
	CDG	948	215	641	1,430
	Δ	- 4	88.7	-310	130

[a] Change in response of dependent variable to dietary inclusion of CDG. Positive value represents an increase in response to CDG and vice versa.

[b] Conversion for 4% fat-corrected milk yield is: milk yield x [0.4 + (15 x milk fat [%]/100)].

[c] Δ-milk true protein in percentage units.

We also evaluated lactational responses to CDG as influenced by dietary protein quality and quantity. Response variables included MY and milk true protein concentration and yield. Again, for each response evaluated the dependent variable was the difference in response of cows fed CDG diet minus CONTROL diet within trial. Fixed variables were CDG concentration of the diet; and, CP concentration and fractions of CP based on origin (corn-based vs. non-corn-based ingredients) of CONTROL and CDG diets. Figure 1 shows classification of dietary CP fractions. We characterized

CP fractions within dietary treatment as: corn CP (CCP; the sum of CP from dietary corn silage, corn grain, corn gluten meal, hominy, etc.) and non-corn CP (non-CCP; the sum of CP from soybean meal, alfalfa, whole cottonseed, etc.), expressed as a percentage of total dietary DM for CDG and CONTROL diets. More details of calculation of these fractions are in Hollmann et al. (2011b). More information about CP fractions are in Table 3.

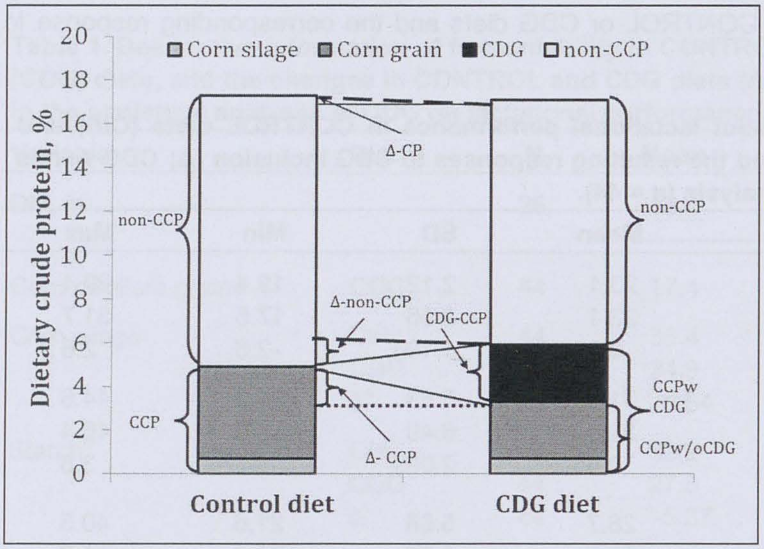

Figure 1. Overall classification of crude protein (CP) fractions in control diet and corn distillers grains (CDG) diet in the database (% of dietary DM)[a].

[a] Adapted from Clark and Armentano, 1997. Concentrations of dietary CP, DM basis, were for CP 17.1% CONTROL diet) and 17.3% (CDG diet). Concentrations of dietary CP-fractions were for corn-based CP (CCP): corn silage (0.7%, 0.7%), corn grain (4.2%, 2.6%), and CDG (CDG-CCP; 0.0%, 2.6%); and for non-corn based CP (non-CCP; 12.2%, 11.4%). Differences (Δ) in concentrations of CP-fractions between CDG diet and CONTROL diets are shown. CCP including CDG-CCP: CCPwCDG; CCP excluding CDG-CCP: CDGw/oCDG.

Table 3. Descriptive information about crude protein (CP) and CP-fractions in CONTROL diets (Ctrl), corn distillers grains (CDG) diets, and the difference in CP fraction (Δ; CDG minus Ctrl) in trials included in the statistical analyses of CDG on lactational performance (n = 44).

Variable	Diet	Mean	SD	Min	Max
		Percent of dietary DM			
Crude protein (CP)	Ctrl	16.6	1.86	13.7	19.7
	CDG	16.8	1.91	13.7	21.0
	Δ[a]	0.21	0.704	- 1.30	3.00
Non-corn based CP	Ctrl	10.8	2.83	6.4	15.6
	CDG	6.3	3.32	0.6	13.2
	Δ	- 4.50	2.402	- 10.3	-0.0
Corn-based CP	Ctrl	5.8	1.23	3.3	7.7
without CP from CDG	CDG	5.2	1.32	3.1	8.3
with CP from CDG	CDG	10.5	2.78	5.0	17.3
CP from CDG only	CDG	5.3	2.73	1.1	12.4
	Δ[b]	- 0.63	0.751	- 2.08	1.96

[a]Change in response of dependent variable to dietary inclusion of CDG. Positive value represents an increase in response to CDG and a negative value a decrease in response.
[b]Corn-based CP (CDG) without CP from CDG minus corn-based CP (Ctrl).

If a value for milk true protein was not provided in the original article, we assumed that 95.25% of milk CP was milk true protein. Additionally, for some analyses the data were split by higher and lower-producing cows at the approximate median (30.0 kg MY/cow per d) of the database to evaluate potential effects of level of milk production.

Results and Discussion

Fermentability Factors and Level of Milk Production

Descriptive information about dietary fermentability factors of CONTROL and CDG diets and the change (Δ) in fermentability factor are in Table 1. Summary information about lactational performance responses of cows fed CONTROL and CDG diets is in Table 2.

Effects on Milk Fat Concentration

Experiences of commercial dairy farms made us suspicious that dietary inclusion of CDG is a risk factor for MFD and that risk is greater when CDG is included in highly fermentable diets. Based on results of this *meta*-analysis, certain qualifiers (e.g., fermentability factors of the diet and level of milk production of cows) help clarify this concern. Overall, inclusion of CDG or concentration of CDG in diets did not consistently affect milk fat concentration response (Figure 2). Yet, milk fat concentration response to CDG was negative when milk fat concentration of cows fed CONTROL diets was greater than 3.58% (Figure 3). Milk fat concentration was less than 3.58% in more than three-fourths of treatment means in the database and dietary inclusion of CDG related to a positive response in milk fat concentration when milk fat concentration of the CONTROL diet within trial was less than 3.58%. However, milk fat concentration in many commercial herds is often greater than 3.58% prior to introduction of CDG into rations. Therefore, the observed negative impact of CDG on milk fat test in the field likely occurs more typically, when basal (before CDG) milk fat concentrations are greater (such as > 3.58%).

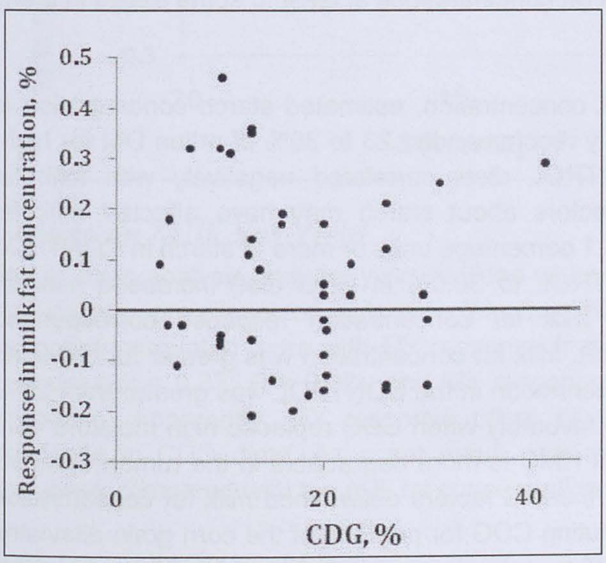

Figure 2. Response in milk fat concentration [corn distillers grains (CDG) diet mean minus CONTROL diet mean within trial] related to CDG for all treatment means (no consistent response).

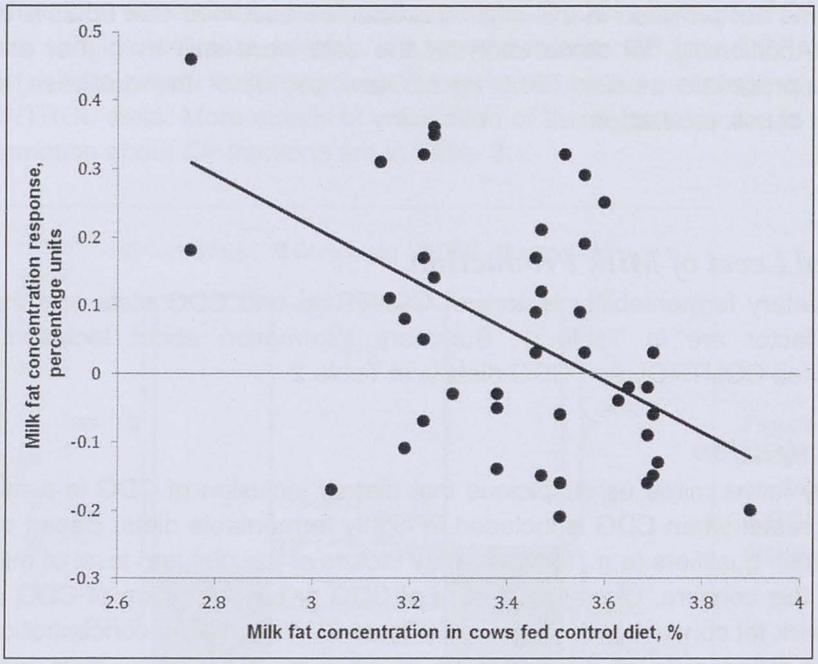

Figure 3. Milk fat concentration response [corn distillers grains (CDG) diet mean minus CONTROL diet mean within trial] to dietary CDG related to milk fat concentration in CONTROL diet (R^2 = 0.26; *P* < 0.001; n = 43).

There was a wide range of milk fat concentration of cows fed CONTROL (2.75% to 3.90%; Table 2). Additionally, milk fat concentration of CONTROL (or prior to introduction of CDG in rations in the field) was relatively low (such as 3.39% as summarized in Schingoethe et al., 2009 or 3.42% in our database). Thus, when CGD is added to diets the **average** magnitude of reduction in milk fat concentration is insignificant. Consequently, the interpretation is that milk fat percentage was not affected by addition of CDG. However, the low original milk fat test (such as 3.39% or great portion of the range in our database) is not typical in many commercial dairies most of the time. Thus, it is improper to suggest that CDG does not affect milk fat concentrations at least to some extent in many herds some of the time.

In our *meta*-analysis, along with the low milk fat concentration, estimated starch concentration in many of the CONTROL diets exceeded commonly recommended 23 to 30% of ration DM for high-producing cows. Starch concentration in CONTROL diets correlated negatively with milk fat concentration (r = -0.36; *P* < 0.001). Three factors about starch may have affected milk fat concentration response to CDG. First, replacing 5.1 percentage units or more of starch in CONTROL diet (e.g., reducing starch from 35.1% in CONTROL to 30.0% in CDG diet) increased milk fat concentration response (Figure 4). Secondly, milk fat concentration response corresponded positively to starch concentration in CONTROL diet. Milk fat concentration was greater for cows fed CDG than for those CONTROL, when starch concentration in the CONTROL was greater than 28%. And third, milk fat concentration responded more favorably when CDG replaced high moisture corn (HMC) compared with dry corn (DC). Starch from HMC is more degradable in the rumen than DC and may contribute to MFD. The combination of these 3 factors determined milk fat concentration response to CDG (*P* < 0.01). Presumably, substituting CDG for portions of the corn grain alleviates potential MFD from higher dietary concentration of cornstarch, especially when HMC was fed. This may partially explain the positive milk fat concentration response in trials with less than 3.58% milk fat in cows fed CONTROL diets.

Low mean milk fat concentration of cows fed CONTROL diets (3.42%) may restrict the applicability of this *meta*-analysis to some commercial farms. Cows in trials in the database averaged 142 days in milk (standard deviation = ± 48) at time of sampling. Thus, the negative correlation of milk fat concentration in CONTROL and milk fat concentration response to CDG is unlikely a result of simple dilution of milk fat in early lactation. More likely, excessive starch or grain concentration of CONTROL diets led to the low mean milk fat concentration.

Increased dietary concentration of linoleic acid introduces an additional risk factor for MFD (Lock, 2010). Corn distillers grains contain approximately 5% linoleic acid. Thus, CDG in rations can alter ruminal biohydrogenation of FA and may increase outflow of *trans*-10 *cis*-12 $C_{18:2}$ from the rumen, especially in combination with highly fermentable diets. This may cause MFD by reducing *de novo* synthesis of FA in the mammary gland. The proportion of milk FA shorter than 18 carbons was less in CDG than in CONTROL diets in several experiments and concentration of *trans*-10 *cis*-12 $C_{18:2}$ or *trans*-10 $C_{18:1}$ in milk fat increased in two of three diets containing CDG in our database. All three variables (milk FA < C_{18}, *trans*-10 *cis*-12 $C_{18:2}$, or *trans*-10 $C_{18:1}$) can be an indicator of MFD.

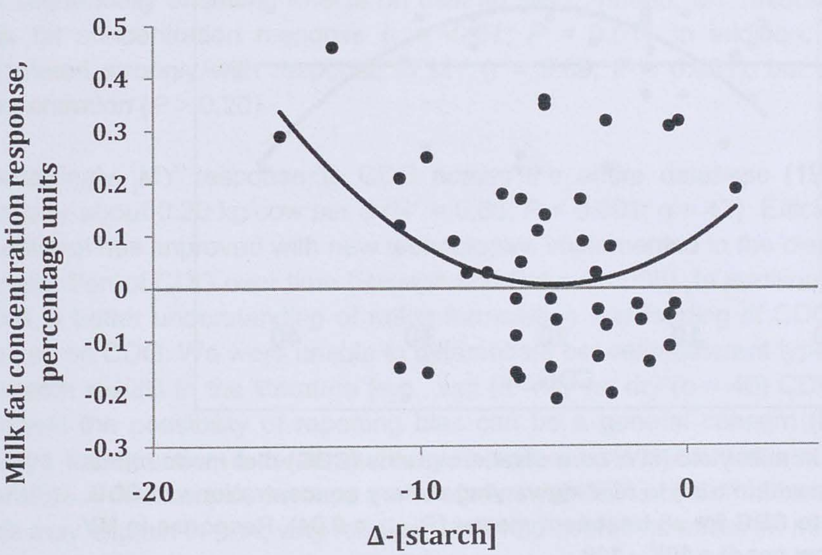

Figure 4. Response in milk fat concentration [corn distillers grains (CDG) diet mean minus CONTROL diet mean within trial] related to substitution of dietary starch. Difference in starch concentration of CDG diet minus CONTROL diet. Negative value for change in starch indicates substitution of starch with CDG (*P* < 0.06).

Effects on Milk Fat Yield

In our *meta*-analysis, milk fat yield declined when CDG was included in diets of cows with low DMI and dietary corn silage concentrations less than 20% or greater than 40% of ration DM. Milk fat yield response correlated more with MY response (r = 0.73; *P* < 0.001) than with milk fat concentration response (r = 0.32; *P* = 0.03), and MY response correlated negatively with milk fat concentration response. Apparently, MY response offset or was not synchronal with milk fat concentration response in CDG diets. As a net result, less variation was accounted for in the milk fat yield response compared with the milk fat concentration or MY responses.

Effects on Milk Yield

Milk yield response to CDG peaked when CDG was about 21 % of total ration DM (Figure 5), but the response was influenced by diet composition. Inclusion of CDG decreased MY when diet fermentability was high (such as when dietary concentrations of corn silage or starch were greater than 47% or 32%, respectively). Nonetheless, it was surprising that factors characterizing diet fermentability (increasing concentrations of corn silage or starch), generally implicated in MFD, better described the MY response in our analysis. Additionally, dietary concentrations of corn silage, cornstarch, and CDG are inseparably confounded with the protein quality of the diet. Diets with high concentrations of CP from corn grain sources may be limited in one or more essential amino acids (NRC, 2001). This limitation may be exacerbated when CDG replaces non-corn sources of CP. The MY response, therefore, may be related to dietary CP quality based on the concentration of CP originating from non-corn sources (vs. corn sources) in the diet. Relationships of dietary CP fractions with lactational responses to CDG are addressed in more detail below.

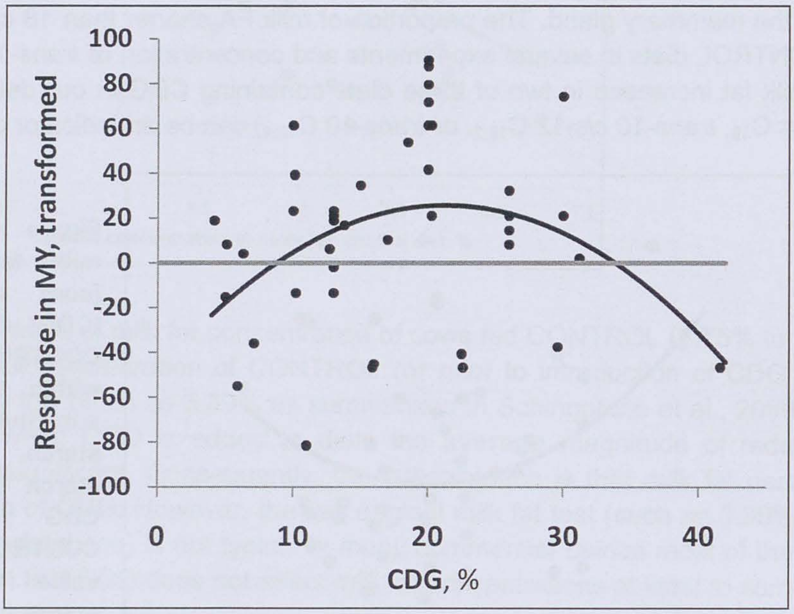

Figure 5. Response in milk yield [MY; corn distillers grains (CDG) diet mean minus CONTROL diet mean within trial] to feeding varying dietary concentrations of CDG. Milk yield response to CDG for all treatment means (P_{model} = 0.04). Response in MY expressed as: [kg/cow per d] + 10)^2 – 100.

Schingoethe et al. (2009) suggested that sufficient dietary forage (such as 50% of dietary DM) prevents decline in milk fat percentage in response to feeding CDG. Based on our *meta*-analysis, dietary starch concentration was associated with milk fat concentration response to CDG diet, but the response was not necessarily related to forage concentration. In general, compositional differences in diets (such as addition of CDG, type of forage, and other feedstuffs) lead to poor repeatability of milk fat percentage responses to dietary treatments (Clark and Armentano, 1997; Firkins, 1997). Non-forage fiber sources, such as CDG, do not stimulate chewing activity (Clark and Armentano, 1997). The corresponding increase in milk fat concentration with non-forage fiber sources was likely due to an alleviation from ruminal acidosis (Clark and Armentano, 1997), as previously discussed. However, forage NDF (ForNDF) concentration is correlated positively with chewing time and milk fat percentage. In our analysis, ForNDF concentration of CONTROL and CDG diets correlated negatively with milk fat concentration response, but positively with MY response. Dietary forage and EE concentrations were confounded in our database (r = -0.76; P <

0.001), likely because concentrates, such as grains, protein ingredients, and feed byproducts, contained more EE than forages. Thus, it was not possible to clearly differentiate responses by dietary ForNDF or EE concentration.

Lower-producing cows are more prone to MFD than higher-producing cows, when fed the same, highly fermentable diet (Bradford and Allen, 2004). Similarly, there was a stronger and more negative correlation between milk fat concentration in CONTROL diets and milk fat concentration response in lower- than in higher-producing cows in our analysis. In contrast, some variables of diet fermentability explained MY response to CDG more consistently in higher- than in lower-producing cows. Level of milk production should be included in determining how much CDG to include in rations, because in our analysis responses in milk fat concentration and DMI were more affected in lower- (MY < 30 kg/cow per d) than in higher-producing cows, whereas MY response was more affected by CDG in higher-producing cows.

In our evaluation, conflicting responses in MY and milk fat concentration led to these factors explaining less variability in 4% fat-corrected milk yield (FCMY) response than in MY response; consequentially offsetting effects on milk fat yield. Indeed, MY response correlated negatively with milk fat concentration response (r = -0.37; P = 0.01). In addition, response in FCMY to CDG correlated strongly with response in MY (r = 0.89; $P < 0.001$), but not with response in milk fat concentration ($P > 0.20$).

Interestingly, MY response to CDG across the entire database (1985 through 2008) increased annually about 0.20 kg/cow per d ($R^2 = 0.66$; $P < 0.001$; n = 43). Efficiency of converting cornstarch to ethanol has improved with new technologies implemented in the distillation process, changing the composition of CDG over time (Rausch and Belyea, 2006). In addition to changes in composition of CDG, a better understanding of ration formulation and feeding of CDG likely led to better research studies on CDG. We were unable to differentiate between different types of CDG, because of lack of research results in the literature [e.g., wet (n = 4) vs. dry (n = 40) CDG]. Finally, as with any *meta*-analysis the possibility of reporting bias can be a general concern (Egger et al., 1997). There is always the question if some studies with unfavorable outcomes are not reported in the scientific literature. For example, perhaps some studies with CDG diets that caused MFD were not published. This may explain in part, why feeding CDG had overall no effect on milk fat concentration response. Often a positive response in milk fat concentration in our database was based on dietary starch concentrations greater than 30% and milk fat concentrations less than 3.6%, which may not be typical in many commercial dairies today.

Effects of Dietary Protein

Descriptive aspects about dietary CP and CP-fractions of CONTROL and CDG diets and the difference (Δ) in CP fractions are in Table 3. Summary information about true milk protein concentrations and yields of cows fed CONTROL and CDG diets and resulting lactational responses is in Table 2.

Effects on Yields of Milk and Milk True Protein

Responses in yields of milk and milk true protein to CDG were not related to dietary concentration of CDG or CP. There is no specific dietary concentration of CDG that maximized yields of milk and milk true protein. However, MY response to CDG was related to the fraction of non-corn-based protein (non-CCP) in the diet and to level of milk production of cows in CONTROL diets. Increasing concentration of non-CCP was associated with greater responses in milk protein concentration, and yields of true protein and milk with maximum responses at greater than 6.5%, or at 8.8% and 8.2% non-CCP, respectively (Figures 6A, B, C). Maintaining milk and milk true protein yields of cows fed CDG diets requires that at least 5% of dietary DM originate from non-CCP. These observations are consistent with the idea of lysine is a limiting amino acid for MY. Increasing lysine intake beyond this amount does not affect milk true protein concentration and yield (NRC, 2001). Vyas and Erdman (2009) concluded that a sufficient concentration of dietary lysine must be provided to maximize milk true protein yield. Based on our results, CDG diets must contain at least 5% non-CCP to maintain yields of milk and milk protein. However, response is maximized when diets are about 8.5% non-CCP.

Concentrations greater than 11% non-CCP reduced lactational responses slightly, but diets with more than 11% non-CCP in addition to CP from corn-based sources **including** CDG (CCPwCDG) will most likely over-supply dietary CP. Dietary concentration of corn-based CP **excluding** CDG (CCPw/oCDG) correlated negatively with milk true protein concentration and yield, and MY responses (Figures 7A, B, C) regardless of concentrations of CDG or CP from CDG. Change in milk protein yield was negative, when diets contained more than 5.5% CCPw/oCDG (Figure 6B). In our analysis, excluding the CP from CDG in the calculation of CCP concentration in the diet explained the variation in lactational responses to CDG better than including CP from CDG. Crude protein concentration in CDG varied more across trials in the current database and between batches from corn ethanol plants (Rausch and Belyea, 2006) than the CP concentration of other corn

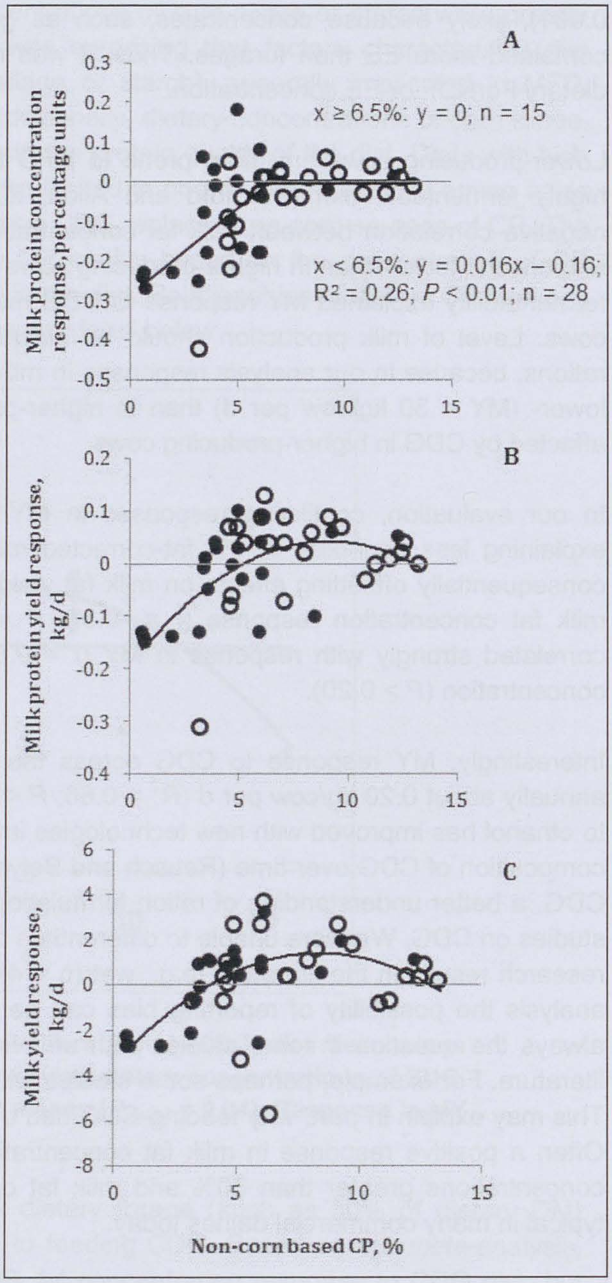

Figure 6. Responses for milk true protein concentration (A), milk true protein yield (B), and milk yield (C) to dietary corn distillers grains (CDG) compared with CONTROL related to concentration of non-corn-based CP in total dietary DM in trials with lower-producing cows (solid circles; < 30.0 kg MY/cow per d) and higher-producing cows (open circles; > 30.0 kg MY/cow per d).

products [e.g., corn silage ± 1.2 percentage units (± SD); or dry corn ± 1.3; (NRC, 2001)]. Moreover, some portions of the CCP in CDG may have been heat-damaged in some trials (Powers et al., 1995; Kleinschmit et al., 2006). Lysine is proportionally more ruminally degraded than other amino acids (Dado, 1999). Thus, the variation in available CP and specifically availability of lysine in CDG is potentially even greater than the variation in CP (Powers et al., 1995; Schingoethe et al., 2009).

Most of the responses to dietary CP quality (corn vs. non-corn source) and their interpretation are based on treatment means of less than 30.0 kg MY/cow per d for CONTROL diets. This binominal classification in the database was based on MY of cows fed CONTROL diets. Thus, deficiency of one or more amino acids in CONTROL diets could have contributed to this classification. Possibly, protein quality (balance of essential amino acids) of CONTROL diets was limiting MY in these trials. Inclusion of CDG could exacerbate the protein limitations in diets resulting in less than 30.0 kg MY/cow per d. Alternatively, milk and milk protein yield responses may have been a consequence of lower DMI as concentration of dietary non-CCP decreased and CCP increased. As a consequence, inclusion of CDG limited lactational performance of lower-producing cows even more.

The non-CCP includes essential amino acids that may be in limiting concentrations in CCP (e.g., lysine). Therefore, if ration is balanced for non-CCP and CP and if excessive N-excretion is a concern, concentration of CCP is fixed. Dietary non-CCP and CCP concentrations were inversely related in our database. Thus, the current findings relating CCP to MY and milk protein yield responses to CDG are secondary to non-CCP concentration, because CDG diets in the database generally were balanced for CP. Therefore, sufficient non-CCP (e.g., 6.5% or more of dietary DM) should be

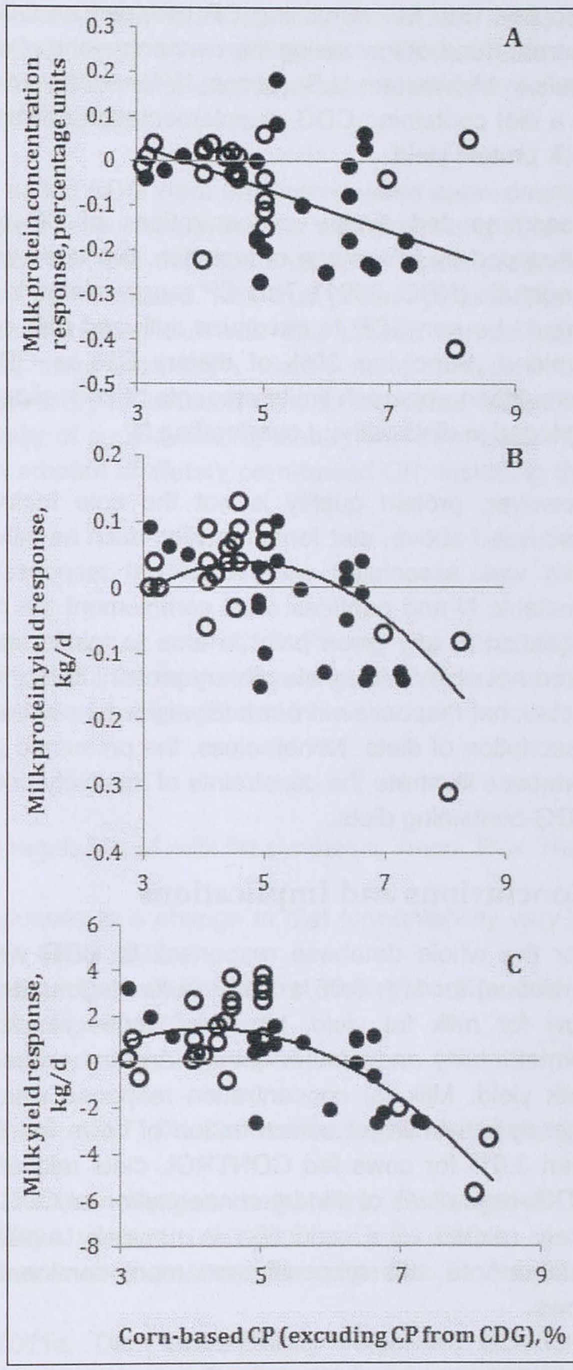

Figure 7. Responses in milk protein concentration (A), milk protein yield (B), and milk yield (C) to dietary corn distillers grains (CDG) compared with CONTROL related to corn-based CP [excluding CP from CDG in total dietary DM in trials with lower-producing cows (solid circles; < 30.0 kg MY/cow per d) and high-producing cows (open circles; > 30.0 kg MY/cow per d).

supplied with the remaining CP provided as CCPwCDG. This recommendation is contrary to the current trend of increasing the concentrations of corn-based feedstuffs such as corn silage and corn grain in Midwestern U.S. rations. If, for economical or availability reasons, less non-CCP is provided in a diet containing CDG, supplementation of lysine that escapes ruminal degradation may improve milk protein yield.

Recommended dietary concentrations of CP for lactating cows range from 13.5 to 18%, as influenced by MY, stage of lactation, live body weight, DMI, degradability of the CP, and available feedstuffs (NRC, 2001). This CP range relates to about 5 to 9.5% CCP, assuming that 8.5% of DM should be non-CCP to maximize milk and milk protein yields and that overfeeding of N should be avoided. Supplying 20% of dietary DM as CDG equates to about 6% CCP. In concept, this formulation approach limits amounts of corn silage, corn grain, and other corn products that can be included in diets without overfeeding N.

However, protein quality is not the sole factor influencing lactational responses to CDG. As discussed above, diet fermentability, such as influenced by starch concentration and fermentability, also was associated with lactational responses to CDG. Moreover, accessibility of ruminally available N and peptides must complement the needs of ruminal microorganisms for carbohydrate digestion at any given point in time to maximize fermentation efficiency (Firkins et al., 2007). We were not able to integrate dietary protein, carbohydrate, and lipid concentrations and relate them to lactational responses in our analysis due to limited number of treatment means in the database and description of diets. Nonetheless, the presumed presence of diets that likely limit MY in the current database illustrate the constraints of relatively poorer dietary protein quality (e.g., lysine deficient) in CDG-containing diets.

Conclusions and Implications

For the whole database responses to CDG were: 0.5 ± 2.10 kg/cow per d (mean ± standard deviation) for MY; 0.05 ± 0.178 percentage units for milk fat concentration; and, 26 ± 77.6 g/d per cow for milk fat yield. However, these results were based on a wide range of diets (e.g., fermentability and protein quality) and subsequently on wide ranges of milk fat concentration and milk yield. Milk fat concentration response was not related to dietary CDG, but was correlated linearly with milk fat concentration of cows fed the CONTROL diet. Milk fat concentration greater than 3.6% for cows fed CONTROL diets related to a negative milk fat concentration response to CDG, regardless of dietary concentration of CDG. Positive responses in milk fat concentration were likely related to a reduction in ruminally available starch when CONTROL diet caused MFD. Furthermore, this response was more dominant in high-producing cows than in lower-producing cows.

Only MY response related significantly to increasing concentrations of CDG in diets. It peaked at 1.2 kg/cow per d with 21% CDG. Diet fermentability was associated with MY response in several ways. Greatest MY response to CDG was with 24% corn silage or 23% starch and concentrations greater than 47% corn silage or 32% starch resulted in negative MY responses. Responses in MY differed by level of milk production and were often more evident in high-producing cows (> 30.0 kg MY/d) compared with lower-producing cows.

When formulating diets with CDG, diet fermentability and level of milk production must be considered. Concentrations of corn silage and starch must be moderate to optimize lactational responses to CDG. Overall, lactational response to CDG in this database was dependent on diet fermentability and milk fat concentration in the CONTROL diet.

Milk yield and milk true protein yield responses to added CDG were maximized when approximately 8.5% of the total dietary CP was non-CCP. Milk yield response peaked for high-producing cows (> 30.0 kg MY/cow per d) at 4.3% dietary corn-based CP, but declined linearly for lower-producing cows (< 30.0 kg/cow per d) as corn-based dietary CP increased. Milk true protein yield response declined as corn-based dietary CP concentration increased but milk true protein concentration response was not affected when CDG diets had more than 6.5% dietary non-corn-based CP. Overall, 8.5% dietary non-corn-based CP was necessary in lactation diets to maximize lactational responses from diets containing CDG. The necessity of supplementing dietary non-corn-based CP to maximize milk and milk protein yields limits the amount of dietary corn-based CP, including that from CDG, that can be included in rations.

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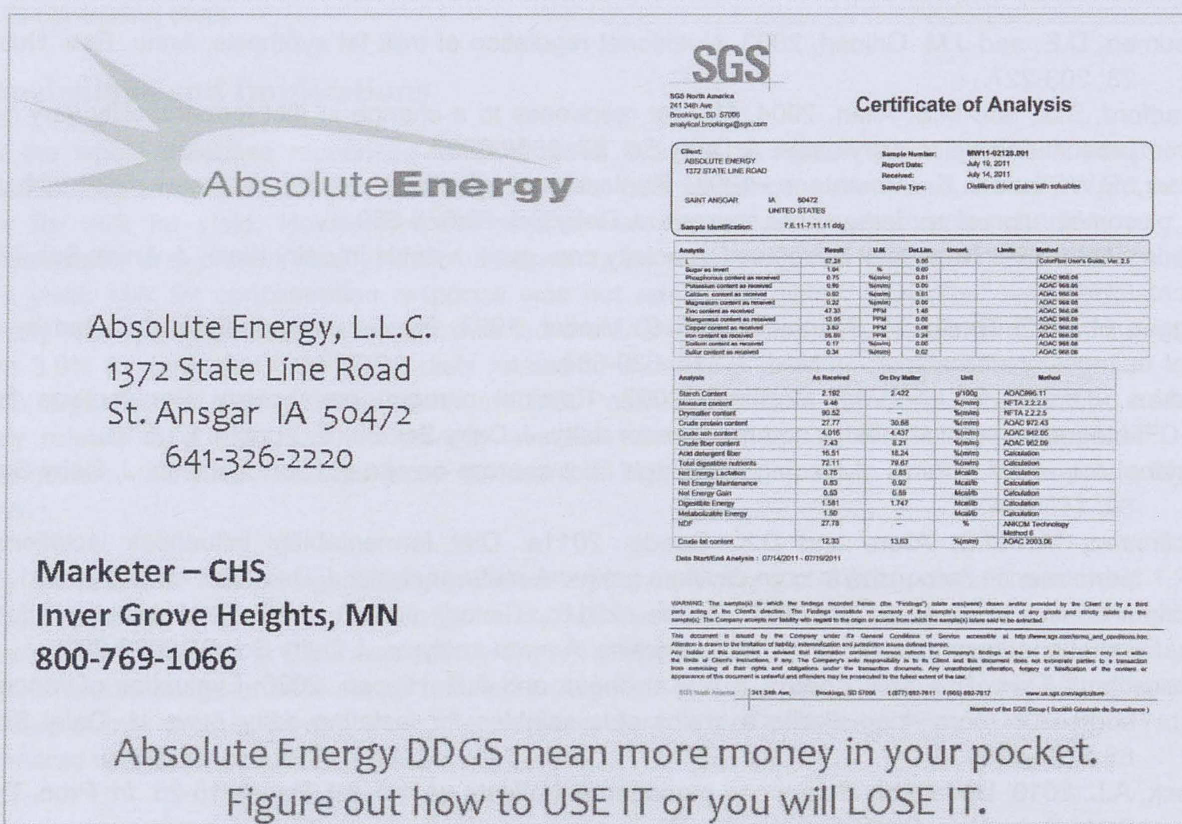

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Certificate of Analysis

Client:
ABSOLUTE ENERGY
1372 STATE LINE ROAD
SAINT ANSGAR IA 50472
UNITED STATES

Sample Number: MW11-02128.001
Report Date: July 19, 2011
Received: July 14, 2011
Sample Type: Distillers dried grains with solubles

Sample Identification: 7.6.11-7.11.11 ddg

Analysis	Result	U.M.	Det.Lim.	Uncert.	Limits	Method
L	57.28		0.00			ColorFlex User's Guide, Ver. 2.5
Sugar as invert	1.04	%	0.00			
Phosphorous content as received	0.75	%(m/m)	0.01			AOAC 968.08
Potassium content as received	0.99	%(m/m)	0.00			AOAC 968.08
Calcium content as received	0.02	%(m/m)	0.01			AOAC 968.08
Magnesium content as received	0.32	%(m/m)	0.00			AOAC 968.08
Zinc content as received	47.33	PPM	1.46			AOAC 968.08
Manganese content as received	12.06	PPM	0.00			AOAC 968.08
Copper content as received	3.62	PPM	0.08			AOAC 968.08
Iron content as received	56.89	PPM	0.24			AOAC 968.08
Sodium content as received	0.17	%(m/m)	0.00			AOAC 968.08
Sulfur content as received	0.34	%(m/m)	0.02			AOAC 968.08

Analysis	As Received	On Dry Matter	Unit	Method
Starch Content	2.192	2.422	g/100g	AOAC996.11
Moisture content	9.48	–	%(m/m)	NFTA 2.2.2.5
Drymatter content	90.52	–	%(m/m)	NFTA 2.2.2.5
Crude protein content	27.77	30.68	%(m/m)	AOAC 972.43
Crude ash content	4.016	4.437	%(m/m)	AOAC 942.05
Crude fiber content	7.43	8.21	%(m/m)	AOAC 962.09
Acid detergent fiber	16.51	18.24	%(m/m)	Calculation
Total digestible nutrients	72.11	79.67	%(m/m)	Calculation
Net Energy Lactation	0.75	0.83	Mcal/lb	Calculation
Net Energy Maintenance	0.83	0.92	Mcal/lb	Calculation
Net Energy Gain	0.53	0.59	Mcal/lb	Calculation
Digestible Energy	1.581	1.747	Mcal/lb	Calculation
Metabolizable Energy	1.50	–	Mcal/lb	Calculation
NDF	27.78	–	%	ANKOM Technology Method 6
Crude fat content	12.33	13.63	%(m/m)	AOAC 2003.06

Date Start/End Analysis : 07/14/2011 - 07/19/2011

Notes