INTERACTION OF GRAIN CO-PRODUCTS WITH GRAIN PROCESSING: ASSOCIATIVE EFFECTS AND MANAGEMENT

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INTRODUCTION

The vast majority of research with corn milling co-products such as distiller's grains (DG) and corn gluten feed (CGF) has been conducted in the Northern Great Plains and Corn Belt with the type of finishing diets commonly fed in that region. More recently these co-products have become available for feeding in the Southern Great Plains. Feedlot diets in the Northern Great Plains differ from those fed in the Southern Great Plains because 1) corn generally is dry rolled rather than steam flaked; 2) supplemental fat is not routinely fed in the Northern as compared with the Southern Great Plains and 3) feedyards tend to be larger in the Southern than the Northern Great Plains. Thus, management and storage of co-products, especially wet co-products, will differ. Moreover, environmental issues tend to differ between the two regions with the Northern Great Plains and Corn Belt being grain-exporting regions whereas, the Southern Great Plains imports grain.

With increased availability of these co-products in the Southern Great Plains, researchers have begun to evaluate their use in finishing diets typical of those fed in that area. Indeed, current research studies indicate that DG has a lower feeding value with steam-flaked corn (SFC)-based diets than with dry-rolled corn (DRC)-based diets (Cole et al., 2006; Erickson and Klopfenstein 2006a, b; Vasconcelos et al., 2007). With diets based on DRC, substituting wet DG for corn improved feed efficiency (Erickson and Klopfenstein, 2006a, b). Erickson and Klopfenstein (2006b) concluded that wet DGS had 110 (50% inclusion) to 150% (10 to 20% inclusion) the energy value of DRC. In contrast, studies in Kansas and Texas (Cole et al., 2006) indicated that DG had energy and feeding values considerably lower than SFC. In contrast to results with DG, with CGF no interaction with grain processing method has been detected.

Knowledge about possible reasons for the interaction between grain processing method and DG could lead to development of economically beneficial management regimens. For example, if the interaction favors DRC, less intensive processing of corn might be used to decrease energy costs; alternatively, cattle feeders may need to modify roughage or fat levels to decrease feed costs and/or digestive disturbances.

IS THERE AN INTERACTION BETWEEN CO-PRODUCTS AND GRAIN PROCESSING?

Our first objective was to examine the validity of the claim that a grain processing x co-product interaction exists. Therefore, data were obtained from 37 reports (published papers and unpublished research progress reports) in which wet DG or CGF was fed. The NEm and NEg values of the basal/control diets were determined using tabular (NRC, 2000) values, DMI, and animal performance data using the quadratic equation of Zinn (1990). The tabular NEm and NEg values of the ingredients in the diets then were adjusted *en masse* to equal the performance-based values. The modified NE values for the feed ingredients then were used to calculate the NE of DG and CGF by substitution. The NE values of co-products also were determined based on chemical composition using average chemical compositions presented by Holt and Pritchard (2004) for DG and by NRC (2000) for CGF using the equations of Zinn and Plascencia (1993) and NRC (2000).

On the average, the composition of the basal/control diets in the DRC-based trials and SFC-based trials did not differ greatly in composition. In general, SFC diets contained more added fat; however, the studies conducted in Texas contained added fat whereas those conducted in Kansas did not. Based on tabular composition of diet components, the DE, NE, CP, DIP, and ether extract values were greater for SFC-based diets than for DRC-based diets. Grain processing did not affect the calculated effective NDF (eNDF), dietary cation-anion balance (DCAB), or mineral composition of the control diets.

Table 1. Average performance by cattle fed the control diets in each trial*

	Wet distiller's grains + solubles			Corn gluten feed		
Item**	DRC	SFC	Std dev	DRC	SFC	Std dev
Initial BW, lb	759	816	69.1	752	693	63.58
Animal performance						
Days fed	130	111	30.1	132	150	19.1
ADG, lb	3.52	3.08	0.55	3.48	3.76	0.42
DMI, lb	23.6	18.4	3.41	22.5	19.6	2.48
DMI, % BW	2.39	1.86	0.32	2.28	2.02	0.23
F/G, lb/lb	6.70	6.00	0.55	6.42	5.18	0.40
MP required, lb/d	1.36	1.32	0.06	1.36	1.40	0.04
MP intake, lb/d	2.07	1.76	0.25	1.96	1.78	0.17
ADG, NE predicted/actual, %	109.6	107.9	14.8	107.2	103.0	14.1
Calculated from performance						
NE_g, Mcal/cwt	55.0	67.2	0.90	57.7	70.4	0.90
DMI, lb/d	20.5	16.6	3.08	20.0	17.9	2.13
Based on tabular values						
NE_g, Mcal/cwt	64.1	75.4	--	65.4	77.3	--

*DRC, dry rolled corn; SFC, steam flaked corn; Std dev, standard deviation.
**BW, bodyweight; ADG, average daily gain; DMI, dry matter intake, F/G, feed/gain; MP, metabolizable protein; NE, net energy; NE_g, NE for gain.

The average performance by cattle fed the control diets in each trial and the calculated NE values are presented in Table 1. In both DG- and CGF-studies, mean DMI was greater in trials where the diet was based on DRC rather than on SFC. The calculated MP intakes of the control diets in each of the 37 studies reviewed appeared adequate. This is significant because if the control diet was deficient in protein, the response to dietary DG additions would be inflated as a result of correcting a deficiency in DIP or MP. The NE values and DMI calculated from animal performance tended to be less than tabular values, but the relative difference between calculated and tabular values were similar for both grain processing methods.

The mean NE values for wet DG and CGF calculated from animal performance in the 37 trials and average chemical composition data are presented in Table 2. The mean NE values for CGF were similar whether the diet contained SFC or DRC. In addition, the performance-based values for CGF were similar to values in NRC (2000) tables and to values calculated from chemical composition. However, the mean NE values for DG were considerably greater when DG was fed in diets based on DRC than on SFC. In addition, the NE values for DG in DRC-based diets tended to be greater than NRC (2000) and chemical composition-based values; whereas, the NE values for DG in SFC-based diets tended to be less than NRC (2000) and chemical composition-based values.

Table 2. Net energy values of wet distiller's grains + solubles and corn gluten feed determined by substitution in dry rolled corn (DRC)-based or steam flaked corn (SFC)-based diets and from tabular (NRC, 2000) values and chemical composition (mean ± standard deviation)

Item*	DRC	SFC	Tabular	Chem. Comp.
Distiller's grains				
NE_m, Mcal/cwt	114.5 ± 15	92.3 ± 29	99.1	107.7
NE_g, Mcal/cwt	80.9 ± 14	61.8 ± 25	68.2	75.9
Corn gluten feed				
NE_m, Mcal/cwt	94.1 ± 10	90.4 ± 14	88.2	89.0
NE_g, Mcal/cwt	63.6 ± 9	61.4 ± 14	59.1	59.5

*NE_m, net energy for maintenance; NE_g, NE for gain.

To ascertain the veracity of these results, performance data from cattle fed the experimental diets were compared to those of control cattle. In studies with DRC-based diets, ADG and G:F of cattle fed DG were 5.7 to 8.3% greater than for control cattle; in studies with SFC-based diets, ADG and G:F of cattle fed DG were approximately 1.2% less than for control cattle. Dry matter intakes of control and treated cattle were similar. With CGF trials, the relative responses of treated vs. control cattle were similar whether the diet was based on DRC or SFC.

In one recent direct comparison of processing methods, Macken et al. (2006) compared the feeding value of diets containing 35% wet CGF and either DR or SF corn. Cattle fed SFC had lower DMI, similar ADG, and greater G:F than cattle fed DRC. These results match what would be expected with diets containing no CGF. Vander Pol et al. (2006a) conducted a similar study with 30% wet DG (DM basis) diets. In contrast to the results of Macken et al. (2006) with CGF, when DG was added to the diet, ADG and DMI by cattle fed DRC was greater than performance of cattle fed SFC-based diets.

Based on these trials, an interaction between grain processing and co-products exists with DG but not with CGF. Several differences exist between DG and CGF; these include DM content (35 vs. 60% for WDG vs. CGF, respectively), CP concentration (31 vs. 24%), DIP concentration (33 vs. 75% of CP), fat concentration (12 vs. 3.9%), NDF concentration (42 vs. 36%), odor/aroma, ethanol content, microbial cell content (i.e., yeasts, etc.), as well as physical characteristics such as particle size and bulk density. The cause for the DG x grain processing interaction presumably lies in one or more of these characteristics. In addition, the benefits in performance which occur in DRC-based diets and/or the adverse effects on performance with SFC-based diets appear to occur at relatively low DG concentration (< 20%). Therefore, the substance within, or property of, DG that produces these effects is apparently provided at these lower concentrations. Thus, our next objective was to examine potential reasons for an interaction between grain processing and DG feeding value, limiting our discussion to factors that would meet these criteria.

POSSIBLE REASONS FOR A PROCESSING-CO-PRODUCT INTERACTION

Lodge et al. (1997) attempted to distinguish the component(s) of DG that accounted for its unexpectedly high calculated NE values with DRC-based diets by formulating a "simulated wet DG" composite comprised of wet CGF, corn gluten meal, tallow, and condensed distiller's solubles. The NEg value for this composite was similar to that of DG and averaged 121% that of DRC. When tallow was removed from the composite, the NEg value decreased to 116% of DRC, and when germ meal was removed, the NEg value decreased to 110% of DRC. However, they were unable to clearly determine to what extent fat, fiber, protein, and undegraded protein affected the response to DG. Lodge et al. (1997) used NRC (1984) energy values for all feed ingredients to determine the NE values of the DG. When the NE values of DRC were calculated based on performance of the control diet cattle, the DRC had a NEg concentration of 0.74 Mcal/lb, a value 104.4% of the NRC (2000) tabular value for DRC.

Potential for improvement: Dry-rolled corn vs. steam-flaked corn

Using NRC (2000) values, Krehbiel et al. (2006) suggested the upper caloric limit for maximizing ADG is 1.44 Mcal ME/lb of DM and for G:F it is 1.56 Mcal of ME/lb. Obviously, if this hypothesis is correct, when energy intake of the control diet in a feeding experiment is near the "maximal," the ability to improve animal performance via feed additives or specific ingredients is limited. In the reviewed trials with DRC-based diets, the mean dietary ME was 1.38 Mcal/lb (Std. dev. = 0.005); in the SFC-based trials the mean ME concentration was 1.55 Mcal/lb (Std. dev. = 0.006). These differences suggest the lack of a performance or efficiency response to DG in SFC-based diets may be the result of the simple fact of cattle already performing near their genetic potential so dietary changes have limited capacity to improve performance. In contrast, with DRC-based diets ME intake is less than optimal so an opportunity exists for improving performance. Similarly, the potential to have adverse associative effects on the utilization of SFC-based diets likely would be greater than for DRC-based diets.

Effects on diet digestibility

Few studies have measured the digestibility of diets containing DG. Wayne Greene and coworkers at the Texas A&M Research and Extension Center in Amarillo (preliminary unpublished data reported by

Cole et al., 2006) noted feeding 5 to 15% DG in SFC-based diets tended to decrease N digestion and urinary N excretion as a percentage of N intake. However, N retention did not differ among diets. Richardson et al. (2006) reported in vitro DM disappearance of 90% concentrate SFC-based diets tended to be less for diets containing 5 and 10% wet sorghum DG than for diets containing 0 or 15% wet sorghum DG. With SFC-based diets, Debenbusch et al. (2005) noted lower apparent total-tract DM (mean 81.5 vs. 83.8%, respectively) and OM (84.4 vs. 86.8%, respectively) digestibilities with diets containing 15% (DM basis) DG than with control diets. With DRC-based diets, Ham et al. (1994) reported diets containing 40% wet DG had apparent total-tract OM digestibilities similar to the control diet (82.8 vs. 81.3 %), but diets with 40% wet DG had greater digestibilities for starch (91.7 vs. 93.9), NDF (62.5 vs. 69.6%), and N (74.9 vs. 79.1%). However, it is not clear how OM digestibility was not improved when digestibility of N, starch, and NDF were increased. Somewhat in contrast to the results of Ham et al. (1994), with DRC-based diets Mateo et al. (2004) reported no effect of either wet or dry DG (20 and 40% of diet DM) on apparent digestibility of DM, OM, N or NDF.

Based on these results, differences in total-tract digestibility do not appear to contribute to the apparent DG x grain processing interaction. However, differences in the site of digestion still might be important. The highly digestible NDF in DG might affect fermentation within the rumen and large intestine, and this effect might be different in DRC- and SFC-based diets. With SFC-based diets little starch survives to be digested in the large intestine, and to inhibit post-ruminal NDF digestion. In contrast, with DRC-based diets digestion of residual starch flowing to the large intestine could depress pH and inhibit NDF digestion in the large intestine. Replacing some of the DRC starch with DG should decrease the quantity of starch reaching the large intestine and allow for greater post-ruminal NDF digestion.

Theoretical effects on starch digestion and utilization

Site of starch digestion may affect the efficiency of utilization of dietary energy from starch. Huntington et al. (2006) noted that the effect varied depending on the extent of ruminal starch digestion and the quantity of starch entering the small intestine. They also proposed that starch digestion/absorption in the small intestine was limited to approximately 1.7 lb/d in growing beef cattle. Ruminal digestibility of starch from DRC is considerably less than from SFC (Owens et al., 1986). Thus, using the equations of Huntington et al. (2006) and Harmon and McLeod (2001) we calculated the theoretical effects of DG on starch utilization and energy obtained from starch intake. These calculations assume that associative effects are absent. Assuming either a constant DMI for all diets or using DMI values from our 18 reviewed studies, DG additions at 20 to 40% of diet DM would increase the efficiency of energy utilization from starch by 3.2 to 4.8% with DRC-based diets vs. 1.7 to 2.4% for SFC-based diets. Thus, based on these assumptions, feeding DG seemed to improve energy utilization of dietary starch with a greater response on DRC-based diets than SFC-based diets.

Variation in chemical composition

The nutrient composition of DG varies both within and across ethanol plants (Table 3; Holt and Pritchard, 2004; Knott et al., 2004a, b). In addition, the source of grain used to make DG (i.e., sorghum vs. corn) can affect the nutrient composition and apparent energy value of DG (Lemon, 2004; Vasconcelos et al., 2007) with the feeding value of DG from sorghum grain being slightly lower than DG from corn. Because sorghum-based DG were used in a number of the SFC-based studies, the NE value of DG when fed with SFC could be lower than when fed with DRC if the DG was from corn when fed with DRC but from sorghum grain when fed with SFC.

In general, the majority of protein from wet DG is not degraded in the rumen (65% UIP). The large variability in acid detergent insoluble nitrogen (**ADIN**) noted by Holt and Pritchard (2004) suggests the ruminal degradation of CP from DG may be highly variable. However, Nakamura et al. (1994) and Klopfenstein (1996) suggested that ADIN was not reliable as a predictor of total tract protein digestibility of DG or of performance of cattle fed DG.

Table 3. Nutrient composition of wet distiller's grains with solubles from three plants in South Dakota (Holt and Pritchard, 2004) and of dried distiller's grains from plants in the Midwest (Knott and Shurson, 2003a, b)

Item	Mean	Minimum	Maximum	SEM*	NRC, 2000
Holt and Pritchard, 2004					
Dry matter, %	31.4	29.52	36.48	0.28	25.0
Crude protein, %	35.5	34.39	36.58	0.25	29.7
Neutral detergent fiber, %	42.3	36.1	48.2	0.51	40.0
Acid detergent fiber, %	12.1	9.81	16.9	0.26	--
Ash, %	3.8	2.75	4.23	0.15	5.2
Fat, %	12.1	11.04	13.12	0.29	9.9
Acid detergent insoluble N, % of N	9.8	7.9	16.5	--	--
Knott and Shurson, 2003a,b					
Moisture, %	11.69	9.67	13.57	0.91	--
Crude protein, %	26.63	24.54	28.42	0.97	29.7
Ether extract, %	10.06	9.20	11.55	0.70	
Crude fiber, %	6.90	5.80	9.10	0.78	

*Standard error of the mean.

Differences in the chemical composition of DG are in a large part due to differences in the grain used in the fermentation. Removal of the starch fraction accentuates relative differences in the grains. Other factors can also affect the chemical composition of DG. Additions of acid (usually sulfuric acid) are sometimes required during the fermentation process to optimize ethanol production. This results in increased sulfur concentrations in the DG produced. The moisture content of DG leaving the plant can also vary from day-to-day depending upon the extent of drying and the quantity of solubles added back to the wet or partially dried grains. The type (in bag or silo, on concrete slab), length, and conditions (open to atmosphere, precipitation, solar drying, etc.) of storage at the feedyard can also affect the moisture content of the final product and the apparent nutritive value.

Effects of fat/caloric density

The fat content of DG can vary from less than 10% to more than 13% of DM (Holt and Pritchard, 2004; Knott and Shurson, 2004a, b). Thus, based solely on fat content, the NEm values of DG calculated from chemical composition (Zinn and Plascencia, 1993) can vary by 5 to 6% (1.04 to 1.10 Mcal/lb for 10 and 13% fat, respectively).

Zinn and Plascencia (1996) reported that animal performance was decreased when fat intake exceeded 0.72 g/lb of BW. Total fat intake did not exceed this level in any of the studies reviewed. Thus, decreased performance caused by excessive fat intake with SFC-based diets probably is not causing the grain processing x DG interaction.

To evaluate the possibility of a fat x DG interaction, Mike Brown and coworkers (unpublished data) at West Texas A&M University currently are studying the effects of fat intake on utilization of wet DG in finishing diets based on SFC. Preliminary results indicate that the NEg of the wet sorghum DG is 0.59 Mcal/lb, a value somewhat lower than suggested by NRC (2000).

Obviously one reason for the high NE values for DG reported in many trials with DRC is the fat provided by DG. Larson et al. (1993) reported that wet DG contained 47% more energy than DRC when fed to yearlings; however, only 9% of the added energy could be attributed to the additional fat from DG added to the diet. With DRC-based diets, the effects of adding fat on animal performance have been variable (Krehbiel et al., 1995; Vander Pol et al., 2006b). In addition, the fat in corn is less saturated than fat from yellow grease or tallow typically supplemented in feedlot diets. Studies with whole cottonseed indicate that fats contained within feed ingredients may be more readily tolerated than supplemental fats. The comparative feeding value of corn oil within DG seems to be similar to that of yellow grease or tallow (Montgomery et al., 2005; Sulpizio et al., 2003).

Some ethanol plants are currently removing some or all of the fat from DG for use as bio-diesel or for other uses. This trend is expected to increase in the future. The effects of fat removal on the feeding value of DG will require additional research. Removal of the fat should produce a product with a chemical composition more similar to CGF; however, the physical properties (particle size, density, etc.) will differ from CGF.

Effects on methane production

Based on the theoretical ruminal fermentation balance of Wolin (1960), Barajas and Zinn (1998), and Corona et al. (2006) calculated that methane production was as much as 37.5% less with SFC-based diets than with DRC-based diets. Wainman et al. (1984) reported that methane production from the ruminal fermentation of distillery products was only half to one-third that of common feedstuffs of "comparable digestibility." Whether those differences are the result of the high fat content of many distiller's products, to the yeast content (McGinn et al., 2004), to effects on ruminal pH (Lana et al., 1998), to the fermentation pattern of the fiber, or to other factors is not clear. This finding suggests, however, that the feeding of DG potentially may decrease ruminal methane production. If ruminal methane production is 37% greater with DRC than SFC (Wolin, 1960; Barajas and Zinn, 1998; Corona et al., 2006), decreasing methane loss would have greater benefit with DRC-based than SFC-based diets. Vander Pol et al. (2006b) reported that the ruminal acetate:propionate ratio was lower when DG was added to DRC-based diets, which would support the concept that methane production is reduced when DG is included in the diet. However, the acetate:propionate ratio may also have been decreased simply due to glycerol present in the DG; as glycerol can be as much as 5% of the DM in DG.

Yeast

Knott and Shurson (2004) noted that up to 3.9% of dried DG weight was yeast biomass and residual yeast metabolites. Although results have been variable, yeast additives contain compounds that potentially are beneficial biologically and immunologically (Yoon and Stern, 1995; Krehbiel et al., 2003; McGinn et al., 2004). To date, no studies have tested the feeding value of yeast or yeast cultures in DRC- and SFC-based diets; therefore, whether yeast might cause a DG x grains processing interaction is not known.

Dietary cation-anion balance

In the studies reviewed, the DCAB increased as the concentration of DG in the diet increased due to the relatively high Na and K concentrations in the DG (Table 4). Ross et al. (1994) reported that ADG increased in a quadratic fashion as DCAB (Na + K – Cl) increased from 0 to 45 mEq/100 g of DM, with optimal performance at 15 mEq/100 g. Higher DCAB can result in greater systemic buffering capacity and a possibility of less sub-clinical and clinical acidosis (Owens et al., 1998). Higher dietary DCAB could potentially explain some of the improvement in animal performance noted with supplemental DG; however, this effect should be more beneficial with diets based on SFC than on DRC because of the more rapid ruminal fermentation of starch from SFC. However, because of higher intake of DRC-based diets, the quantity of starch digested in the rumen may be similar in DRC- and SFC-based diets.

Table 4. Dietary cation-anion balance (mEq/100 g of dry matter) of diets containing varying concentrations of wet distiller's grains (DG)*

% DG in diet (DM basis)	(Na+K)-Cl	Std dev.	(Na+K)-(Cl+S)	Std. dev.
0 (n = 14)	3.80	2.75	-7.58	3.94
5-14 (n = 2)	5.89	2.08	-5.51	3.53
15-25 (n = 12)	7.07	3.46	-6.23	3.71
26-40 (n = 16)	14.61	3.62	-0.66	2.48
> 40 (n = 3)	20.82	0.88	1.99	0.50

*DM, dry matter; Std. dev., standard deviation.

Effects of crude protein, ruminally degraded protein, and metabolizable protein

Results of several performance studies indicate cattle fed SFC have higher DIP requirements (as a % of the diet) than cattle fed DRC (Cooper et al., 2002a; Galyean, 1996; Gleghorn et al., 2004). Barajas and Zinn (1998) noted for SFC but not DRC, the NE values were affected by the protein source (urea vs. cottonseed meal) and/or concentration (11% for urea vs. 14% for CSM). In contrast, using cannulated steers, Cooper et al. (2002b) reported that the DIP requirement was similar for cattle fed diets composed of DRC and SFC but approximately 12% lower than for calves fed diets composed of high-moisture corn.

The post-ruminal amino acid supply of cattle fed DRC-based diets is potentially deficient when urea is the sole protein supplement because of limited ruminal microbial protein synthesis. In addition, DRC-based diets that contain corn silage, rather than alfalfa, as a roughage source could provide less metabolizable protein. To examine protein concentration effects on calculated grain energy values, Fred Owens (personal communication) plotted the calculated ME value of DRC and SFC (based on animal performance) vs. dietary CP using the data set from the grain processing review of Owens et al. (1997). The results (Figure 1) indicate that calculated ME values of DRC are not affected by dietary CP concentrations above approximately 11.5%, whereas, calculated ME values of SFC decreased as CP values decrease from 13.5 to 11%. This suggests that the ME value of SFC, but not DRC, could be decreased if dietary DIP concentrations are decreased by the addition of DG. Although the calculated metabolizable protein intakes of the control diets were adequate in the 37 studies we reviewed, because these values are based solely on tabular values, they could be misleading.

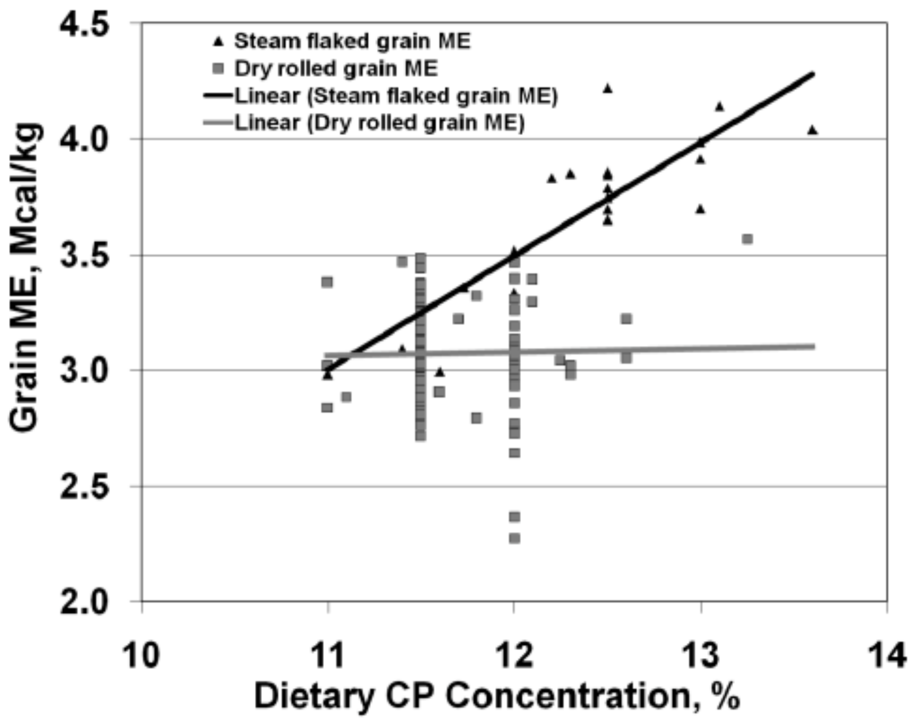

Figure 1. Plot of grain metabolizable energy (ME) concentration (calculated from animal performance) and dietary crude protein (CP) concentration (F. Owens, personal communication) using the data set of Owens et al. (1997).

With isonitrogenous, SFC-based diets Lemon (2004) reported that DG had adverse effects on animal performance when DG concentrations exceeded 10% of dietary DM. Analyzed dietary CP concentrations were less than the formulated value of 13.5% CP, ranging from 11.71 to 12.29%. Therefore, Galyean and coworkers hypothesized that the poor performance of DG cattle in the study of Lemon (2004) was due to a DIP deficiency. However, adding urea to replace the DIP lost when DG was substituted for corn and urea failed to improve animal performance (Shaw, 2006; Vasconcelos et al., 2007: Table 5). These results suggest the DG x grain processing interaction is not the result of a DIP deficiency.

Although in vivo studies are less conclusive (Cole and Todd, 2007), results of some in vitro experiments indicate that for optimal utilization of dietary energy and nitrogen the rate of release of both components from feeds in the rumen need to be synchronized (Taniguchi et al., 1995). It is not known whether the rate of release of N from DG within the rumen is more advantageous with DRC-based diets than with SFC-based diets. Recycling of N to the rumen from the lower gut, as well as other physiological changes such as altered feeding patterns and rate of passage, may be adequate to compensate for a deficiency in DIP and/or may adequately synchronize ruminal energy and N availabilities (Cole and Todd, 2008). If synchrony is important, increased synchrony might have a greater benefit with DRC-based than SFC-based diets because of less ruminal fermentation with DRC leaving more starch to reach the large intestine for fermentation. Ruminal synergy might also be affected by the rate of passage, but it is not know if, or how, DG and CGF may alter the rate of passage.

Table 5. Effect of degradable intake protein (DIP) replacement on performance of cattle fed steam-flaked corn-based diets containing 0 (control) or 10% wet distiller's grains + solubles with increasing crude protein (CP) and DIP concentrations (Shaw, 2006)

Item[a]	Control	0% of DIP	50% of DIP	100 % of DIP
Diet CP, % DM	12.95	13.25	14.01	14.68
Diet DIP, % DM	8.41	7.23	7.83	8.40
Diet UIP, % DM	5.09	6.27	6.27	6.30
ADG, lb	3.78	3.70	3.54	3.45
DMI, lb	20.3	20.4	19.8	19.2
F:G	5.38	5.52	5.59	5.56

[a]Analyzed values for CP and formulated values (NRC, 2000) for DIP and UIP. DM, dry matter; UIP, undegradable intake protein; ADG, average daily gain; DMI, dry matter intake; F:G, feed:gain.

In a number of studies with DRC-based diets, CP concentrations of diets containing DG reached 20% with no apparent adverse effect on animal performance. In contrast, Gleghorn et al. (2004) noted that feeding high concentrations (14.5%) of protein to cattle on SFC-based diets could adversely affect animal performance and decrease calculated dietary NE values. Thus, the increased dietary CP from adding DG might possibly decrease NE values in SFC- but not in DRC-based diets.

Effects on subclinical acidosis

Based on the studies with CGF by Krehbiel et al. (1995), several authors have proposed that a portion of the beneficial effects on performance when feeding corn co-products can be attributed to a decrease in the incidence of subclinical acidosis. In contrast, with DRC-based diets Ham et al. (1994) and Vander Pol et al. (2006a) reported that ruminal pH was lower in steers fed DG-containing diets than in steers fed the control diet. Thus, based on studies with small numbers of animals fed DRC-based diets, effects of DG on subclinical or clinical acidosis might be small or nonexistent.

Moreover, a decrease in subclinical acidosis is not likely to be the cause of the grain-processing x DG interaction because the benefit should be greater with a more rapidly fermented starch source like SFC than with less rapidly degraded starch from DRC. Contrarily, if DG reduces ruminal pH as noted previously, then DG should increase the incidence of subclinical acidosis more for cattle fed the more readily fermented SFC. Also, one might expect the added fat from DG to attenuate ruminal starch fermentation. If fat is already included in the diet, as it typically is in SFC diets, no further benefit would be expected from fat in the DG containing diets.

Effects on feed/energy intake

Averaged across the experiments summarized, DMI was not affected by including DG in the diet. Nonetheless, in some individual studies, including DG in diets based on DRC significantly increased DMI. In general, however, it seems that improvements in performance with the feeding of wet DG were not the result of increased feed intake. Also, although ADG and G:F might be improved by increased DMI, the calculated NE values for DG should correct for differences in DMI.

Effects of ethanol in the wet distiller's grains

Using DG produced in a small university-scale unit, Larson et al. (1993) reported that the ethanol concentration of wet DG was 10.7% (DM basis); private consultants (anonymous, personal communication) have reported that ethanol concentration was as high as 11% (DM basis) in commercially available wet DG.

Results of studies that have evaluated the feeding value of ethanol to ruminants have produced variable results. Burroughs et al. (1958) reported that ethanol supplementation improved animal performance. Kreul et al. (1993) reported that ADG was increased by 25% in steers limit-fed diets containing 0, 2, 4, or 6% ethanol. However, when steers were given free choice access to feed, ethanol (4% of dietary DM) failed to improve performance. Ham et al. (1994) reported that ADG and DMI by lambs fed DRC-based diets containing 0, 5, or 10% ethanol were not affected by ethanol although G:F decreased linearly as ethanol concentration in the diet increased. Larson et al. (1993) reported that when G:F of steers fed DG was adjusted for ethanol intake (method not described) improvements in G:F ranged from 5 to 20%. Thus, presence of ethanol in wet DG potentially could increase the energy value of DM by 10% or more if the ethanol has a feeding value equal to grain and the ethanol is lost when measuring the DM concentration. However, benefits should be similar whether the basal diet is based on DRC or SFC.

Mineral toxicities or interactions

Distiller's grains can contain high concentrations of certain minerals and mycotoxins that are concentrated during the fermentation process. The NRC (2000) maximum tolerable level for dietary S is 0.40% of DM; however, with SFC diets, Zinn et al. (1997) reported that performance was depressed for calves fed diets containing 0.25% S from ammonium sulfate. Feeding a high concentration of DG in the diet potentially would produce dietary S concentrations that meet or exceed the maximum tolerable level. Unfortunately, S concentrations in diets are rarely reported in the literature. Reduction of sulfate to the more toxic sulfide form of S in the rumen is increased at lower pH values with accumulation of hydrogen sulfide in the gas cap of the rumen (Gould, 1998). Thus, the potential for S toxicity might be greater in diets based on SFC than in DRC-based diets. In addition, use of other co-products or supplements rich in S, such as molasses, or having high S concentrations in drinking water might exacerbate negative effects of S in co-products.

Effects on ration integrity and physical characteristics of the diet

Factors such as moisture, bulk density, particle size of diets, and digestible NDF concentration can affect mixing efficiency, ingredient segregation during handling, diet consistency, rumination/salivation, ruminal turnover rate, rate of passage, feed intake variation, and site of digestion (Pritchard and Stateler, 1997). Wet DG in diets could have either beneficial or detrimental effects on diet characteristics and the response might differ between DRC-based diets vs. SFC-based diets because particle size of DRC- and SFC-based diets will differ (Scott, et al., 2003; Corona et al., 2006). Knott and Shurson (2004b) noted that the mean particle size (mean 1,282 µm; range 612 to 2,125 µm; CV = 24%) and bulk density (mean 28.6 lb/ft^3; range 24.7 to 31.6 lb/ft^3; CV = 7.8%) of dried DG varied considerably from one ethanol plant to another. In addition, wet DG tends to have a smaller particle size than CGF (Lodge et al., 1997).

With addition of wet DG or GCF to dry diets, separation of fine particles in the mixer or feed bunk should be decreased: this could potentially help to reduce acidosis. If particle separation is a greater problem with DRC-based diets than with SFC-based diets, especially without added fat, then more benefit might be expected with DRC-based diets than SFC-based diets.

Potential effects of research methods

Differences in experimental methods (storage of DG and/or SFC, bunk management, weighing conditions, lab analyses, etc.) and(or) experimental errors could potentially produce a grain processing x DG interaction. If so, it is not apparent whether the interaction is the result of an "overestimation" of DG feeding value in DRC-based diets, an "underestimation" of its value in SFC-based diets, or some combination of these two. However, this grain processing x DG interaction has been noted in trials from Nebraska, Kansas, and Texas and interactions between wet CGF and grain processing have been absent in trials both in the Northern and Southern Plains.

Storing wet co-products, even for a short time, can result in a change in the DM concentration. Because of the high moisture content of DG and CGF, even a small error in DM calculation results in an appreciable error in the calculated NE values (Table 6). Wet DG also can contain appreciable quantities of volatile compounds, such as ethanol. Thus, the method used to determine the DM content of wet DG can affect the apparent DM content (Thiex and Richardson, 2003) and subsequent NE estimates. Storing DG in bags potentially should decrease variation in moisture content over time and(or) might allow some anaerobic fermentation to occur. However, Kalscheur and Garcia (2005) suggested fermentation of DG within silo bags was minimal because of the low pH of DG when added to the bag.

Table 6. Effects of errors in dry matter (DM) concentration of co-product on true diet formulation and calculated net energy values if diets are formulated assuming a 30% DM value for wet distillers grains (DG)

Formulated % corn, DM basis	True DM %	True % DG in diet	True % corn in diet	Calculated NE_m*, Mcal/cwt
If DG = 10% of diet DM				
80% corn	25	8.33	81.4	109
80% corn	30	10	80	91
80% corn	35	11.67	78.7	78
If DG = 30% of diet DM				
60% corn	25	26.32	63.2	109
60% corn	30	30	60	91
60% corn	35	33.33	57.1	78

*Net energy for maintenance.

CONCLUSIONS

An interaction / associative effects between grain processing and feeding of wet distiller's grains has been detected in several trials, but no interaction exists for wet corn gluten feed. Potential reasons for the interaction between grain processing method and distiller's grains in the diet would include effects of dietary fat/energy, ethanol contamination, yeast effects, reduced methane production, errors in dry matter concentrations, and numerous other possibilities. Because of the inherent variability in nutrient composition of wet distiller's grains and its high moisture content, the true feeding value of DG probably is quite variable and may differ from one source or one load to another. Additional research is needed to determine how best to employ these co-products in beef cattle finishing diets and their potential to alter the need for grain processing and level of dietary roughage needed.

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QUESTIONS AND ANSWERS

Q: Andy, your cation-anion balance calculations were based on sodium, potassium and chloride. Bill Tucker's work would suggest that half the sulfur should be included in that calculation as an anion. How would including sulfur alter the calculations? Has anyone monitored urinary pH as an index of metabolic acidosis conditions with feeding of distillers' products?

A: Although the actual calculated DCAB values decreased when sulfur values from NRC were included in the calculation, the trends were similar because of the high Na and K concentrations in DG. I am not aware of anyone measuring urinary pH or fecal pH with feeding of distillers' grains.

Additional comment by Erickson: We are making some measurements on this now.