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Feeding Corn Milling Byproducts to Feedlot Cattle

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Corn milling byproducts are expected to increase dramatically in supply as the ethanol industry undergoes rapid expansion. Two primary types of milling processes currently exist, resulting in different feed products. The dry milling process produces distillers grains plus solubles (DGS), and the wet milling process produces corn gluten feed (CGF). These feeds can be marketed as wet feeds, or they can be dried and marketed as either CGF (DCGF) or dry distillers grains (DDG) with or without solubles. For the purposes of this article, wet CGF (WCGF), wet distillers grains plus solubles (WDGS), DGCF, and dried distillers grains plus solubles (DDGS) are discussed. The term DGS is used for undifferentiated discussion about WDGS and DDGS. Most ethanol plant expansions are dry milling plants that produce DGS; however, an increase in supply of WCGF is also expected. These feeds may therefore be very attractive for feedlots to use as feed sources. This article focuses on the production, composition, feeding values, and economics of using these co-products in feedlot situations. Management strategies are discussed, including grain processing, roughage levels when these byproducts are used in feedlot diets, and feeding combinations of WDGS and WCGF. Storage methods for wet products and manure management from byproduct feeding are also explained.

Wet milling

Wet milling is a process that requires use of high-quality (No. 2 or better) corn in which the corn kernel is fractionated to produce numerous products

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intended for human use. Fresh water enters the milling system in the final stage of starch washing. Subsequently, it runs countercurrent with respect to the flow of corn, passing through numerous screens and separating implements, acquiring soluble nutrients at each step. Ultimately, this solution is the resource in which corn entering the process is initially steeped. Lactic acid–producing bacteria in the steeping process ferment the soluble carbohydrates collected by the water to further kernel softening. Following the steeping process (Fig. 1), corn kernels are separated into corn bran, starch, corn gluten meal (CGM, protein), germ, and soluble components. If the wet milling plant is fermenting starch into ethanol, a portion of the steep water (now called steep liquor) is added to the fermentation vat to supply nutrients for the growth of ethanol-producing yeast cells. The ethanol is distilled off after the fermentation process. The solution exiting the still is called distillers solubles, not to be confused with dry milling distillers solubles. Wet milling distillers solubles contains very little corn residue, almost no fat, and is high in protein from the remnants of yeast cells from the fermentation process. The distillers solubles and a portion of the steep liquor are added to the bran fraction of the corn resulting in WCGF. The WCGF can have a portion of the germ meal added if the plant has those capabilities. For a more complete review of the wet milling process, the reader is referred to Blanchard [1]. The actual composition of WCGF can vary depending on the plant's capabilities. Steep, a combination of steep liquor and distillers solubles, contains more energy (136% the feeding value of corn) and protein than corn bran or germ meal [2]. Plants that apply more steep to corn bran or germ

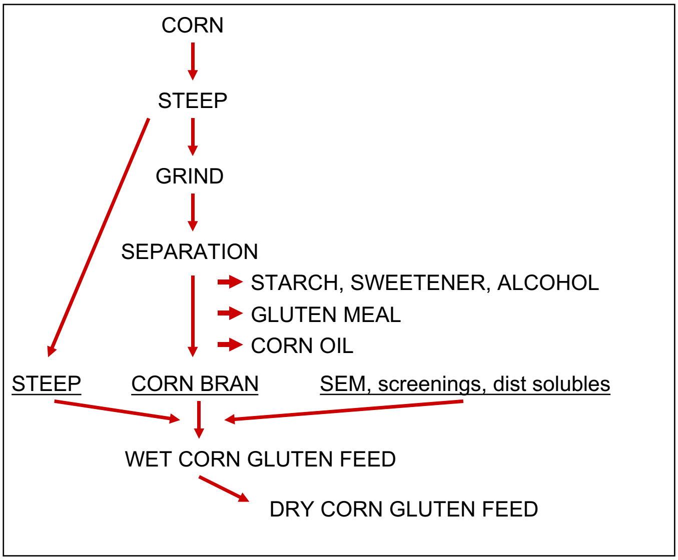


Fig. 1. Wet milling industry resulting in wet or dry corn gluten feed.

meal therefore produce WCGF that is higher in crude protein (CP) and energy.

WCGF contains 16% to 23% CP, which is approximately 70% ruminally degradable protein (degradable intake protein, DIP) used by rumen microbes. During wet milling, CGM is removed and marketed in higher-value markets. CGM should not be confused with WCGF, because CGM contains approximately 60% CP, which is 40% DIP and 60% bypass protein (undegradable intake protein, UIP).

Dry milling

The dry milling ethanol process (Fig. 2) is relatively simple. Corn (or another starch source) is ground, fermented, and the starch converted to ethanol and CO_2. Approximately one third of the dry matter (DM) remains as feed product following starch fermentation, assuming the starch source is approximately two-thirds starch. As a result, all the nutrients are concentrated threefold because most grains do contain approximately two thirds starch. For example, if corn is 4% oil, the WDGS or DDGS contains approximately 12% oil. In the dry milling process, the resultant feed byproducts are distillers grains, distillers solubles, and distillers grains plus solubles, depending on the plant and whether it is producing wet or dry byproducts and the relative amounts of distillers grains and distillers solubles mixed together to be added back to the grains. If all of the solubles are added back to the grains, DGS are 81% distillers grains and 19% distillers solubles (DM basis) [3]. Most distillers grains contains some solubles, but this can vary from plant to plant. Solubles are a good source of protein, high in fat, phosphorus (P), and sulfur (S) and low in fiber [3]. Solubles contain

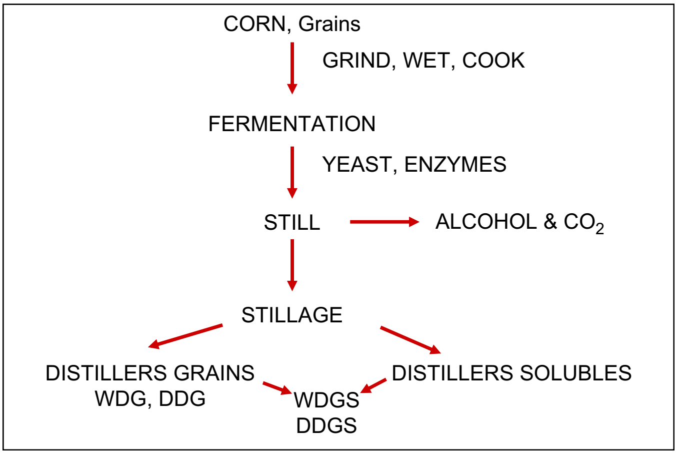


Fig. 2. Dry milling industry with the feed products produced.

25% CP, 20% fat, 1.57% P, 0.92% S, and 2.3% neutral detergent fiber (NDF). Distillers solubles has become a popular base for liquid feed supplements. As molasses prices have increased, many liquid supplement companies are using wet milling industry steep or dry milling distillers solubles in place of molasses in their supplements. In addition, solubles may replace corn and protein in finishing diets [4,5]. Steers fed 4% or 8% of diet DM as corn distillers solubles had improved feed conversion compared with steers fed a conventional cracked corn diet.

The wet milling industry is more complex than dry milling because the corn kernel is divided into more components in wet milling to allow for higher value marketing of end products. For example, the oil is extracted and sold separately in the wet milling industry, as is CGM. CGM is a protein supplement that contains a large amount of bypass protein, or UIP, commonly marketed to the dairy, poultry, or pet industries. The importance of understanding the differences involved in the manufacturing processes is that the resulting feed byproducts from these two industries are different.

Composition

Table 1 contains data on production plant averages and some indication of variation for various corn milling byproducts. Variation exists from plant to plant and even within a given plant. These table values should not replace sampling and analysis of feed from individual plants. The DDGS, WDGS,

Table 1
Nutrient composition of selected corn milling byproducts

	Feedstuff							
	DRC[a]	WCGF-A	WCGF-B	DDGS[b]	WDGS[b]	CCDS[b]	MWDGS	Steep[c]
DM	90	44.7	60.0	90.4	34.9	35.5	46.2	49.4
CP, % of DM	9.8	19.5	24.0	33.9	31.0	23.8	30.6	35.1
UIP, % of CP	60	20	20	65	65	65	65	20
P, % of DM	0.32	0.66	0.99	0.51	0.84	1.72	0.84	1.92
NEg, Mcal/lb[d]	0.70	0.70	0.76	0.82	0.91	0.87	NA	0.95

Abbreviations: CCDS, condensed corn distillers solubles (corn syrup); DDGS, dried distillers grains + solubles; DRC, dry-rolled corn with National Research Counsel (1996) values [29]; MWDGS, modified wet distillers grains + solubles; steep, steep liquor from wet milling plants; NEg, net energy for gain; WCGF-A, wet corn gluten feed; WCGF-B, Cargill Sweet Bran wet corn gluten feed; WDGS, wet distillers grains + solubles.

[a] DRC values based on National Research Counsel (1996) values [29] with approximately 3500 samples.

[b] Values are from spring 2003 from only one plant in Nebraska that produces DDGS, WDGS, and CCDS with standard deviation based on weekly composites.

[c] DM values represent variation from daily composites for a 60-day period. Other nutrients are based on monthly composites for 2002 and half of 2003.

[d] NEg values are based on animal performance relative to DRC. WDGS and DDGS NEg values depend on dietary inclusion.

and condensed corn distillers solubles (CCDS) are all from one plant in Nebraska and represent average values for 2003. Examples of plants with an excellent database on variability are the Cargill Blair, Eddyville, and Dalhart facilities. The standard deviations are low on DM change from load to load. This relates to two things: process development to minimize variation and the quality control culture of personnel operating the plants to minimize variation in feed products. The energy values used in Table 1 are based on performance data summarized in this paper and other reviews.

The DDGS composition data in Table 2 are based on the relative ratios of dried distillers grains to solubles ratio in DDGS [3]. The ethanol plant's normal DDGS averaged 19% solubles. For the purposes of this study, however, distillers grain products were produced with varying levels from 0% to 22% solubles added back to the grain portion. Increasing the amount of solubles decreased the DM, CP, and NDF content of the DDGS. The fat level increased in the DDGS as more solubles were added, however. As more solubles were added back from 0% to 22%, the resulting DDGS went from a golden-yellow color to a brown color. The change in color was not related to total digestive tract protein digestibility, however, because the protein was 97% to 98% digestible in all samples. For another recent review of composition and variation within plants and across plants, the reader is referred to Holt and Pritchard [6]. Moisture and DM variation are probably of greatest importance with wet byproducts. Fat and sulfur levels can vary in DGS, however, which could lead to changes in feeding value and potential for toxicity (especially polioencephalomalacia), respectively.

Feeding value

The first units of byproducts added to a ration are primarily used to replace protein normally provided by urea or natural protein sources in the ration. Subsequent additions of byproducts to the ration replace corn and other grains as energy sources. Feedlot diets that use DGS at levels less

Table 2
Nutrient composition and protein digestibility of dried distillers grains plus solubles based on solubles level

	Solubles level, % (DM)[a]				
	0	5.4	14.5	19.1	22.1
DM, %	96	92	91	89	90
CP, %	32	32	32	31	31
NDF, %	37	35	32	30	29
Fat %	71	9	10	13	13
CP digestibility, %[b]	97	97	98	98	98

[a] Level calculated using % NDF of solubles (2.3%) and 0% solubles DDG.
[b] Situ total-tract protein digestibility.

than 15% to 20% of diet DM serve as a protein source for the animal. Conversely, when DGS is added above these levels, the beef animal uses the DGS as an energy source.

The feeding value of DGS and CGF depends on whether the byproducts are fed wet or dry and the level of dietary inclusion. Although the feeding value of WCGF is better than corn (100% to 109% the feeding value of corn), the feeding value of DCGF is 88% of dry-rolled corn (DRC) when fed at 25% to 30% of diet DM respectively [7].

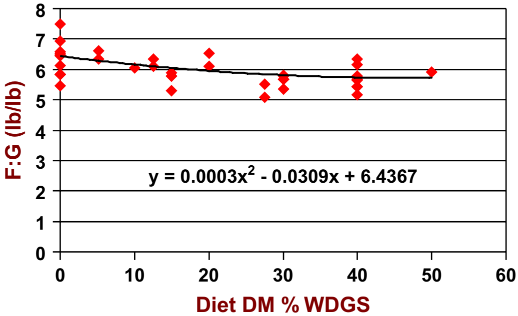
Most of the research on distillers grains as a feed source has been conducted on finishing cattle. Numerous studies evaluating the use of wet distillers byproducts in ruminant diets are available [4,8–19]. Feeding WDGS results in better performance than DDGS (Table 3). In studies with finishing cattle, the replacement of corn grain with WDGS consistently improved feed efficiency (Fig. 3). Fig. 4 summarizes University of Nebraska studies conducted on WDGS with feeding value expressed relative to corn. The feeding value of WDGS is consistently higher than corn. These studies suggest a 30% to 31% improvement in feed efficiency when WDGS replaces intermediate levels of DRC in the diet (15% to 40% of diet DM). The feeding value of WDGS at low levels (less than 15%) is approximately 160% the feeding value of corn. When higher levels of WDGS are used (greater than 40%), the feeding value was still greater than corn. Replacing DRC with WDGS results in a quadratic improvement in ADG (Fig. 5). The optimal biologic response in average daily gain (ADG) was at 30% WDGS inclusion (see Fig. 5).

Buckner and colleagues [20] conducted a 145-day feedlot finishing study to evaluate steer performance with 0%, 10%, 20%, 30%, and 40% dietary DM inclusion of DDGS in corn-based diets. There was a quadratic response in performance. The 20% DDGS diet had the most improved performance when compared with a traditional no-byproduct diet, with a feeding value of 126% the value of corn (Table 4). All DDGS levels had improved feed–gain ratios (F:G) and feeding value relative to the no-byproduct diet. The biologic optimum level of DDGS to feed with DRC and high-moisture

Table 3
Feeding value of wet versus dry distillers grains

			DDGS[a]		
	Control	WDGS	Low	Medium	High
Daily feed, lb	24.2[b,c]	23.56[b]	25.3[c]	25.0[a]	25.9[a]
Daily gain, lb	3.23[b]	3.71[c]	3.66[c]	3.71[c]	3.76[c]
Feed:gain ratio	7.69[b]	6.33[c]	6.94[d]	6.76[d]	6.90[d]
Improvement					
Diet	—	21.5		11.9	
Distillers versus corn	—	53.8		29.8	

[a] Level of acid detergent insoluble N: 9.7%, 17.5%, and 28.8%.
[b,c,d] Means in same row with different superscripts differ ($P < .05$).



Predicted Values	
WDGS Level	F:G
0	6.44
10	6.16
20	5.95
30	5.81
40	5.74
50	**5.73**

Fig. 3. Feed conversion of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

corn (HMC) is less than with WDGS. The biologic optimum levels for the dry and wet DGS are 20% and 30% respectively.

Studies evaluating the use of WCGF replacing DRC or HMC in feedlot diets are also available [2,8,21–24]. Distinct differences exist for WCGF, even within companies, because of plant-to-plant variation. Stock and colleagues [25] divided WCGF into two main categories, depending on the ratio of steep to bran in the final product. Based on differences in the amount of steep added, WCGF has 100% to 109% the feeding value of DRC when fed at levels of 20% to 60% of diet DM [25]. Higher feeding value (and protein) is associated with increases in steep added in WCGF. Feeding WCGF results in better performance than feeding DCGF [26]. In studies with finishing cattle, the replacement of corn grain with WCGF consistently improved feed efficiency (Fig. 6). Replacing DRC with higher feeding-value WCGF in feedlot diets linearly improves ADG (Fig. 7).

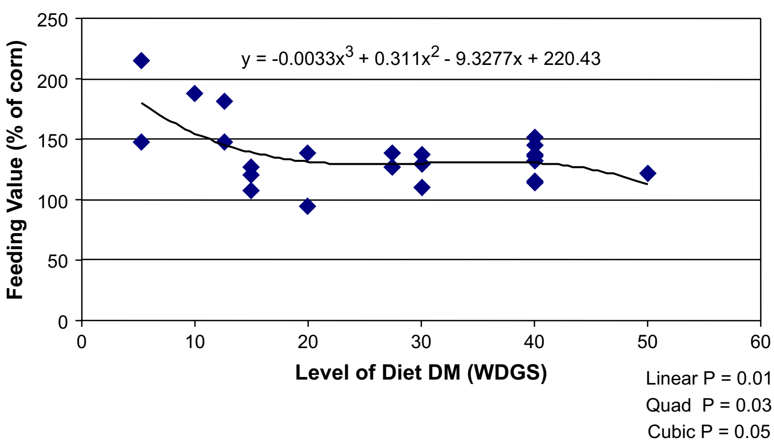


Fig. 4. Feeding value of wet distillers grains plus solubles when replacing corn at different inclusions.

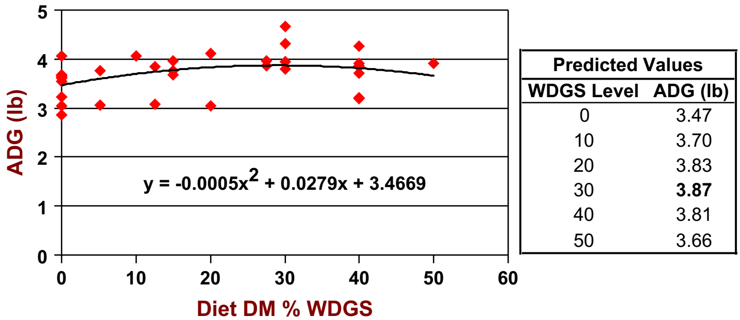


Fig. 5. Average daily gain of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

The improved animal feeding performance from byproduct feeds translates into improved Quality Grade for steers fed DRC- or HMC-based diets [27]. Because the byproduct diets have improved feeding values relative to corn, the cattle gain weight more quickly than corn-fed feedlot cattle. These cattle therefore require fewer days on feed to reach the same backfat and marbling endpoints. Byproduct-fed cattle consuming intermediate levels (10% to 40% diet DM) of WDGS or WCGF for the same number of days on feed as conventional corn-fed cattle are slightly fatter (Figs. 8 and 9) and have more marbling than corn-fed cattle (Figs. 10 and 11). The improved marbling is attributable to improved daily gains. Feeding diets that help cattle fatten more rapidly (ie, byproduct diets) improves the Quality Grade of feedlot cattle compared with traditional diets fed the same number of days.

In certain production situations, light weight (less than 750 lb) finishing cattle may need to be supplemented with UIP (bypass) protein to meet metabolizable protein (MP) requirements. Wet or dry DGS is an excellent source of UIP. The values obtained from feeding trials for UIP are shown in Table 5. Wet grains were compared with dry grains and the value of

Table 4
Performance measurements for cattle fed increasing levels of dried distillers grains plus solubles

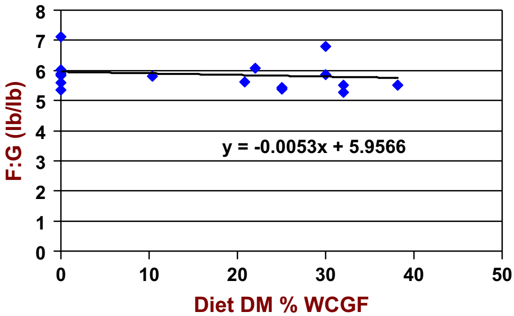
Parameter	CON	10DDGS	20DDGS	30DDGS	40DDGS
DMI, lb	20.8	21.8	20.8	21.2	20.7
ADG, lb[a]	3.29	3.55	3.71	3.56	3.56
Feed:gain[b]	6.32	6.15	5.60	5.93	5.77
Feed value, %[a,c]	—	124	126	108	108

Abbreviations: CON, 0% DDGS; 10DDGS, 10% DDGS; 20DDGS, 20% DDGS; 30 DDGS, 30% DDGS; 40DDGS, 40% DDGS.

[a] Quadratic response to level of DDGS in the diet ($P = .08$).

[b] Linear response to level of DDGS in the diet ($P = .07$).

[c] Calculated with iteration process for net energy calculation based on performance.

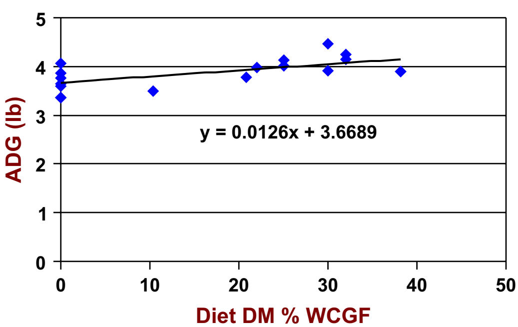


Predicted Values	
WCGF Level	F:G
0	5.96
10	5.90
20	5.85
30	5.80
40	5.74

Fig. 6. Feed conversion of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.

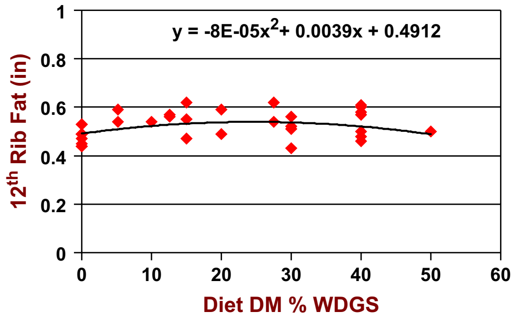
the protein was similar (Table 6). This similarity suggests that the high escape protein value of DGS is attributable to the innate characteristics of the protein and not to drying or moisture content and does not seem to be influenced by acid-detergent insoluble protein (ADIN), which is a common measure of heat-damaged protein.

The crude protein in dry distillers grains is approximately 65% UIP; consequently, diets that include dried distillers grains fed as an energy source are commonly deficient in DIP while containing excess MP. Cattle convert excess MP to urea, which is potentially recycled to the rumen and can serve as a source of DIP. Vander Pol and colleagues [28] fed DDGS to finishing cattle at either 10% or 20% of diet DM. No advantage was observed between cattle supplemented with urea (DIP) or not, suggesting recycling was occurring in these diets. Some numerical differences suggested a conservative approach would be to follow National Research Council (NRC) 1996 guidelines [29] for DIP supplementation if DGS are provided at less than 20% of diet DM.



Predicted Values	
WCGF Level	ADG (lb)
0	3.67
10	3.80
20	3.92
30	4.05
40	4.17

Fig. 7. Average daily gain of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.



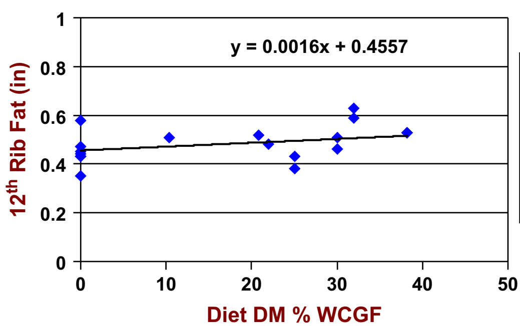
Predicted Values	
WDGS Level	FAT
0	0.49
10	0.52
20	0.54
30	0.54
40	0.52
50	0.49

Fig. 8. Backfat thickness of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

Interaction of corn processing and byproduct feeding

Feeding corn milling byproducts in feedlot diets reduces acidosis-related problems. WCGF and WDGS have little to no starch remaining following the milling process. Feeding these byproducts dilutes whatever starch is fed in other dietary components, therefore, and has an influence on rumen metabolism. Krehbiel and colleagues [30] observed a decrease in subacute acidosis when WCGF was fed to steers in metabolism studies. In many studies, feeding WCGF results in increased dry matter intake (DMI), which would be considered a response to removing subacute acidosis.

Because processing corn increases rate of digestion by microbes, rumen acid production and the risk for acidosis is increased [31]. Feeding WCGF helps prevent the risk for acidosis with high-grain diets [30]. Numerous studies have been conducted at the University of Nebraska to determine if feeding values are markedly improved in diets containing WCGF when corn is more intensely processed. Scott and colleagues [24] evaluated various corn-processing techniques and observed improved feed conversions as



Predicted Values	
WCGF Level	FAT
0	0.46
10	0.47
20	0.49
30	0.50
40	0.52

Fig. 9. Backfat thickness of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.

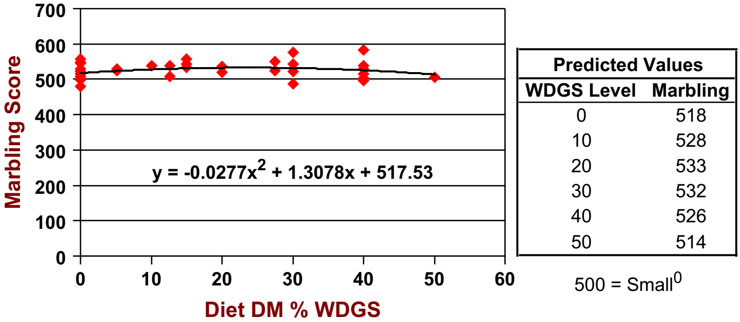


Fig. 10. Marbling score of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

processing intensity increased when feeding calves or yearlings (Table 7). Ranking of processing based on feed conversions (lowest to highest) was whole corn, DRC, HMC, and steam-flaked corn (SFC) when fed to finishing calves. Relative improvements in F:G for DRC, HMC, and SFC compared with whole corn were 6.8%, 11.1%, and 12.5%, respectively. When fed to yearlings, response to processing was not as favorable as with calves. Feeding HMC did not significantly improve F:G compared with DRC. Macken and colleagues [32] fed DRC, SFC, and HMC processed as either rolled (roller mill, RHMC) or ground (tub grinder, GHMC) to calves, with all diets containing 25% WCGF. Performance was more significantly improved the more intensely the corn was processed. Net energy calculated from performance [29,33] was increased by 9.1%, 11.0%, and 14.9% for RHMC, GHMC, and SFC, respectively, compared with DRC.

HMC seems to have greater feeding value when diets contain WCGF than what was previously observed in diets not containing WCGF. Because HMC has greater ruminal starch digestibility than DRC or SFC [34], cattle fed HMC have a greater potential for acidosis when HMC is fed alone.

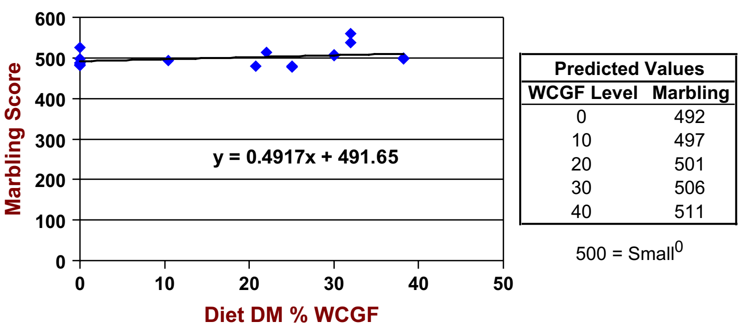


Fig. 11. Marbling score of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.

Table 5
Escape protein values

Source	Protein escape (%)
Soybean meal	30
Wet distillers grains	60–70
Dried distillers grains	60–70
Distillers solubles	30

Feeding HMC in combination with WCGF, however, seems to increase efficiency of use of HMC, perhaps by reducing acidosis. For example, the feeding value of HMC in diets containing HMC as the only grain source is lower than that observed when fed in combination with other grains [35] or corn byproducts. Previous reviews reported that HMC feeding resulted in 2% greater efficiency than DRC [36]. Based on work with HMC-based diets containing 20% to 35% WCGF, however, cattle are 5% to 10% more efficient than those fed DRC and WCGF. Our conclusion is that intense processing has tremendous value in diets containing WCGF.

Optimal corn processing in diets containing WDGS seems to be somewhat different than diets containing WCGF, however. Vander Pol and colleagues [37] fed diets containing 30% WDGS with either whole, DRC, HMC, a 50:50 blend of HMC and DRC (DM basis), or SFC to finishing steers for 168 days. Cattle fed DRC, HMC, or the combination of HMC and DRC gained more and were more efficient than cattle fed whole corn (Table 8). Cattle fed SFC did not gain as efficiently. Corrigan and colleagues [9] investigated feeding DRC, HMC, or SFC in diets containing 0%, 15%, 27.5%, or 40% WDGS. They found greater performance response to WDGS inclusion in diets based on DRC and HMC (Fig. 12). Optimal ADG and F:G were seen with 40% WDGS in DRC-based diets, 27.5% WDGS in HMC-based diets, and 15% WDGS in SFC-based diets. In addition, when diets contained 40% WDGS with DRC the cattle performed just as efficiently as cattle on the SFC diets. A greater performance response to WDGS inclusion in diets based on less intensely processed grain may render them an economically attractive alternative to diets based on more intensely processed grains. It is unclear why steam flaking did not improve

Table 6
Wet and dry distillers grains for calves

Supplement	ADG	Protein efficency[a]	ADIN
Urea	1.00	—	—
WG	1.46	2.6	—
DDGS	1.42	2.0	9.7
DDGS	1.47	1.8	17.5
DDGS	1.54	2.5	28.8

Abbreviation: ADIN, acid detergent insoluble N.
[a] Pounds gain/lb supplemental protein.

Table 7
Effect of corn processing when fed with wet corn gluten feed

25% WCGF

	Processing method			
	DRC	RHMC	GHMC	SFC
ADG, lb	4.23	4.21	4.24	4.33
F:G, DM	5.49[a]	5.13[c]	5.05[c]	4.91[d]
NEg (corn), Mcal/cwt	70.0	76.4	77.7	80.4
Fecal starch, %	19.2[a]	10.6[b,c]	8.4[c]	4.1[d]

32% WCGF with calves

	Processing method			
	Whole	DRC	RHMC	SFC
ADG, lb	4.18	4.24	4.15	4.25
F:G, DM	5.92[a]	5.52[b]	5.26[c,d]	5.18[d]

22% WCGF with yearlings

	Processing method		
	DRC	RHMC	SFC
ADG, lb	3.98[a]	4.02[a]	4.22[b]
F:G, DM	6.09[a,b]	5.97[b]	5.54[c]

Abbreviations: DRC, dry-rolled corn; GHMC, ground high-moisture corn; NEg, net energy for gain; RHMC, rolled high-moisture corn; SFC, steam-flaked corn; whole, whole corn.

[a,b,c,d] Means with different superscripts differ ($P < .05$).

Data from Scott TL, Milton CT, Erickson GE, et al. Corn processing method in finishing diets containing wet corn gluten feed. JAnim Sci 2003;81:3182–90; and Macken C, Erickson G, Klopfenstein T, et al. Effects of corn processing method and crude protein level with the inclusion of wet corn gluten feed on finishing steer performance. Prof Anim Scient 2006;22(1): 14–22.

performance when diets contained WDGS at inclusion levels similar to WCGF inclusion levels.

Interaction of roughage and byproduct feeding

Roughages are often included at low levels (<12% of diet DM) to control acidosis and maintain intake in feedlot cattle [30]. Because byproducts reduce the occurrence of acidosis in feedlot cattle, then perhaps roughage levels may be reduced from conventional levels in diets containing byproducts. Farran and colleagues [13] fed either 0% or 35% WCGF with either 0%, 3.75%, or 7.5% alfalfa hay at each level (ie, WCGF levels and hay levels were factorialized). There was a significant interaction between WCGF and alfalfa level for feed conversion; therefore, only simple effects are presented in Table 9. With 0% WCGF, increasing alfalfa level increased ADG and DMI with no effect on feed conversion. With 35% WCGF, increasing alfalfa hay increased ADG and DMI, but hindered (increased) feed conversion linearly. It seems that roughage can be decreased in

Table 8
Effect of corn processing when fed with wet distillers grains

	Processing method				
	Whole	DRC	DRC/HMC	HMC	SFC
DMI, lb/d	23.1[a]	22.6[a]	21.5[b]	21.0[b,c]	20.4[c]
ADG	3.85[a]	4.05[b]	3.91[a,b]	3.89[a,b]	3.59[c]
F:G	6.07[a]	5.68[b,c]	5.61[b,c]	5.46[c]	5.76[b]

30% WDGS included in all diets.

Abbreviations: DRC, dry-rolled corn; HMC, high-moisture corn; SFC, steam-flaked corn; whole, whole corn.

[a,b,c,d] Means with different superscripts differ ($P < .05$).

Data from Vander Pol K, Erickson G, Greenquist M, et al. Effect of corn processing in finishing diets containing wet distillers grains on feedlot performance and carcass characteristics of finishing steers. Nebraska Beef Report 2006;MP88-A:48.

DRC-based diets that contain 35% or more WCGF. The ADG was reduced for the 0% hay, 35% WCGF treatment, so a small amount of roughage is recommended even when WCGF is included. Similar results have been observed with SFC-based diets in which alfalfa can be reduced to 2% when fed with at least 25% WCGF [38]. Parsons and colleagues [39] observed no change in feed conversion when roughage was decreased from 9% to 0% alfalfa in SFC diets with 40% Sweet Bran WCGF. In their study, DMI and ADG decreased linearly as roughage level decreased, however. Just as with data in conventional corn-based diets, optimum amount of roughage seems to depend on grain processing and level of WCGF.

Benton and colleagues [40] fed alfalfa hay, corn silage, or corn stalks as the roughage source in 30% WDGS (DM basis) diets. Each of the sources was included at a conventional level and one half that level (Table 10). The

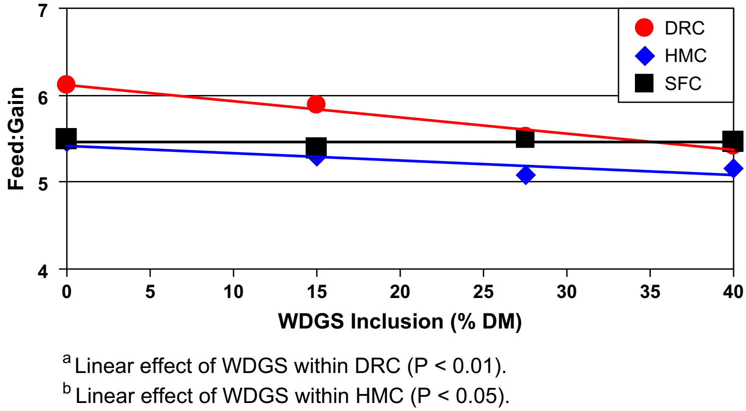


Fig. 12. Feed:gain of WDGS with different corn processing types. (*a*) Linear effect of WDGS within DRC ($P < .01$). (*b*) Linear effect of WDGS within HMC ($P < .05$).

Table 9
Effect of increasing alfalfa hay level in diets with and without wet corn gluten feed for finishing yearlings fed dry-rolled corn–based diets

	0 % WCGF			35% WCGF		
	Alfalfa level					
	0	3.75	7.5	0	3.75	7.5
DMI[a]	22.7	23.8	24.2	23.3	24.9	25.6
ADG[a]	3.68	4.01	4.01	3.94	4.07	4.07
Feed:gain[b]	6.21	5.95	6.02	5.95	6.10	6.25

[a] Nonsignificant interaction between WCGF and alfalfa level; significant ($P < .10$) increase due to WCGF; significant ($P < .03$) linear increase for alfalfa level.

[b] WCGF × alfalfa level interaction ($P < .09$); linear effect ($P < .06$) of alfalfa level within 35% WCGF; no effect of alfalfa hay with 0% WCGF.

normal level was equal to 8% alfalfa hay and the low level was equal to 4% alfalfa hay. In general, normal roughage levels resulted in higher DMI, ADG, and profit. Steers fed 3% corn stalks performed similarly to steers fed normal levels of roughage, however. When roughage was eliminated from the 30% WDGS diets, DMI, ADG, and profit were decreased compared with diets containing cornstalks or normal levels of alfalfa or corn silage. It is not beneficial, therefore, to completely eliminate roughage sources from finishing diets containing 30% WDGS (DM basis).

Wet byproducts allow the use of lower-quality roughages because they contain considerable protein and because the moisture minimizes sorting of all ingredients, especially the lower-quality roughages. The lower-quality roughages have higher fiber contents so diets should be formulated by their fiber content. Small amounts of roughage, equal to 3% to 4% alfalfa hay, should be included in diets with wet byproducts to ensure good levels of DMI and ADG.

Table 10
Effects of roughage source and level compared with no roughage inclusion on performance of steers fed diets containing 30% wet distillers grains plus solubles

	Treatments						
	CON	LALF	LCSIL	LCSTK	NALF	NCSIL	NCSTK
Roughage inclusion[a]	0.0	4.0	6.1	3.0	8.0	12.3	6.1
DMI, lb	22.3[w]	24.4[x]	24.3[x]	25.0[x,y]	25.7[y]	25.3[y]	25.6[y]
ADG, lb	4.33[w]	4.54[w,x]	4.52[w]	4.79[y]	4.76[x,y]	4.75[x,y]	4.80[y]
F:G	5.14	5.37	5.36	5.20	5.41	5.33	5.32
Profit over CON, $[b]	0[w]	9[w,x]	9[w,x]	31[y]	23[x,y]	27[x,y]	29[y]

Abbreviations: CON, control; LALF, low alfalfa hay; LCSIL, low corn silage; LCSTK, low corn stalks; NALF, normal alfalfa hay; NCSIL, normal corn silage; NCSTK, normal corn stalks.

[a] Inclusion level of each roughage source in the finishing diet (DM basis).

[b] Profit: treatment final steer profit accounting for initial steer cost, health cost, yardage, interest and death loss minus control finished steer profit.

[w,x,y,z] Means in a row with unlike superscripts differ ($P < .05$).

Combinations of byproducts

With the large expansion of ethanol plants in the Midwest, an option for many feedlots is using both WDGS and WCGF concurrently. In addition to their commercial availability, another reason for feeding a combination of WDGS and WCGF is their nutritional profiles. Complementary effects in feeding a combination of these byproducts might be expected because of differences in fat, effective fiber, and protein components. Loza and colleagues [41] fed yearling steers a 50:50 blend of WDGS and WCGF (DM basis) at inclusion levels of 0%, 25%, 50%, and 75% of the total diet DM. All inclusion levels of the blend were evaluated with 7.5% alfalfa hay in the diets. Additional treatments were also evaluated using a lower alfalfa level with each of the byproduct diets, decreasing the forage inclusion as the rate of inclusion of byproducts in the diets increased (ie, 25% blend had 5% alfalfa in the lower forage treatment, 75% blend had 0% alfalfa in the lower forage treatment). Results indicated that there were no differences in cattle performance between forage levels for each byproduct blend level. The lack of differences in performance with decreasing forage would indicate that the byproduct inclusion was enough to prevent the negative consequences of subacute acidosis (Table 11). The analysis of the pooled data from each byproduct level indicated that the performance of the steers fed the maximum byproduct level (75%), regardless of the forage level, was not different than a typical corn-based diet (0% byproduct blend). The diets including either 25% or 50% of the blend of WDGS and WCGF resulted in significantly better animal performances than the control, however.

Buckner and colleagues [8] fed the same combination at 30% or 60% dietary DM compared with feeding the byproducts alone at 30% dietary DM or a 0% byproduct diet. The 30% WDGS diet gave the best performance. Feeding WCGF or WDGS in a blend (1:1 on a DM basis) or alone improved performance over control-fed cattle. A second trial by Loza and colleagues [42] compared a 0% byproduct diet to six other diets containing a constant amount of WCGF (30% diet DM) and additions of WDGS at

Table 11
Effect of different inclusion levels of a 50:50 blend of wet corn gluten feed and wet distillers grains plus solubles (dry matter basis) and forage levels fed to yearling steers

	0% DM*	25% DM		50% DM		75% DM	
	7.5**	5	7.5	2.5	7.5	0	7.5
DMI, lb/d	24.3^{a}	26.3^{b,c}	26.5^{b}	25.4^{c}	26.1^{b,c}	23.0^{d}	23.6^{a,d}
ADG, lb/d	3.99^{a}	4.70^{b}	4.57^{b}	4.55^{b}	4.56^{b}	3.86^{a}	3.93^{a}
Feed:gain	6.10^{a}	5.60^{c}	5.80^{b,c}	5.59^{c}	5.73^{b,c}	5.97^{a,b}	6.01^{a,b}

All diets contain a 50:50 DRC–HMC blend and 5% supplement.

^{a,b,c,d} Means with different superscripts differ ($P < .05$).

* Blend.

** Alfalfa.

0%, 10%, 15%, 20%, 25%, or 30% diet DM. Including WDGS at 15% to 20% of the diet with 30% WCGF had the greatest average daily gain. This research agrees with Buckner and colleagues [8] in that the 30% WCGF plus 30% WDGS gave better performance than the corn-based control diet. These three studies demonstrate that high levels of byproducts, when fed in combination, can be fed to feedlot cattle without reducing performance compared with corn-based control diets.

Feeding a combination of WDGS and WCGF can also serve as a management tool. A major challenge facing some ethanol plants is not having byproduct available for cattle feeders on a consistent basis. Cattle do not respond well if either WDGS or WCGF, as a sole byproduct in the diet, is removed and replaced abruptly with corn. One approach would be to feed a combination to ensure that at least one byproduct is consistently in the ration.

Economics

An economic model has been developed for determining economic returns when feeding byproducts in corn-based finishing diets [43]. Performance responses from University of Nebraska feedlot research trials were used to predict DMI, F:G, and ADG. User-defined inputs of cattle prices and weights, byproduct inclusion rates, trucking costs, and yardage costs allow flexibility in generating the expected returns from using byproducts in a given feeding situation. The base assumptions include: corn price is $3.70, byproducts are purchased at 95% the price of corn on a DM basis, feedlot cattle are fed a base ration containing DRC and HMC, and steers are gaining 560 lb over the finishing period. This model suggests the optimum level of WDGS is 30% to 40% of diet DM when feedlots are within 30 miles of the ethanol plant (Fig. 13). As the distance increases from the plant to the feedlot, the optimum inclusion of WDGS decreases to 25% to 35%. This comparison suggests that more WDGS can be fed than levels

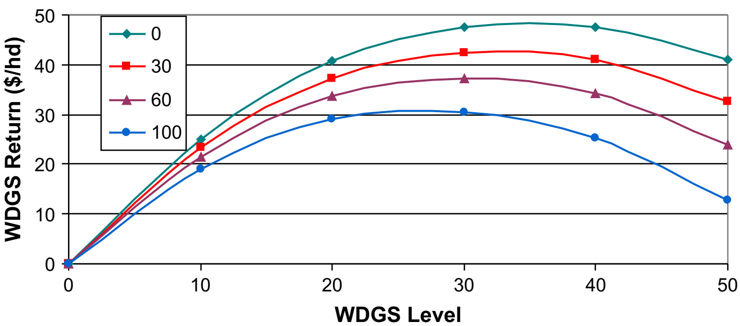


Fig. 13. Economic return from feeding WDGS when fed at 0%, 10%, 20%, 30%, 40%, or 50% of diet DM at 0, 30, 60, or 100 miles from an ethanol plant.

currently being fed; however, the optimum inclusion depends on more than just the feeding value of WDGS.

Modeling DDGS with $3.70 corn has a response curve similar to the WDGS curve at 60 miles; however, the economic optimum seems to be at approximately 20% dietary inclusion of DDGS (Fig. 14). This figure is lower than the optimum inclusion for WDGS with the same assumptions. The increase in economic returns from feeding DDGS as corn price increases is consistent with similar corn price changes for WDGS and WCGF. The returns from feeding Sweet Bran WCGF increase as the level of WCGF increases in the diet (Fig. 15). This response is consistent for feedlots 0 to 100 miles from the plant. These data clearly show that factors such cattle performance, distance from the plant, and corn price influence the economic optimum inclusion rate of byproducts in feedlot rations. This Excel spreadsheet model is available for personal download at http://beef.unl.edu under "byproducts feed" section.

Environmental issues

Animal manure and commercial fertilizers are sources of phosphorus (P) in agricultural runoff that may cause environmental pollution. Including byproducts in rations increases the P concentration resulting in significantly greater P in manure. Inclusion of WDGS at 40% diet DM produces a 90% increase in P excretion. Feeding DGS diets that contain elevated levels of dietary P require more astute manure management plans than feeding conventional corn-based diets without supplemental P. Traditional manure management programs have been based on crop nitrogen (N) needs. Transitioning to an annual crop P requirement rate requires five times more land to spread manure. Spreading manure on a 4-year P-based crop rate only requires a modest increase in labor, equipment, and land cost over traditional annual N-based manure application to crops. The $25 to $48 of cattle profit from feeding WDGS occurred at a cost of about $3 to $5 per finished animal because of increased manure management costs, depending on

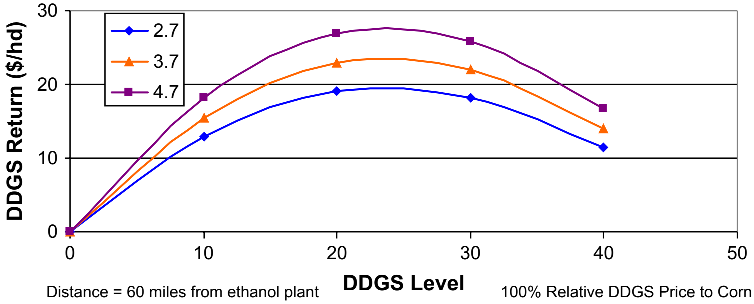


Fig. 14. Economic return from feeding DDGS when fed at 0%, 10%, 20%, 30%, or 40% of diet DM 60 miles from an ethanol plant at $2.70, $3.70, or $4.70 per bushel corn.

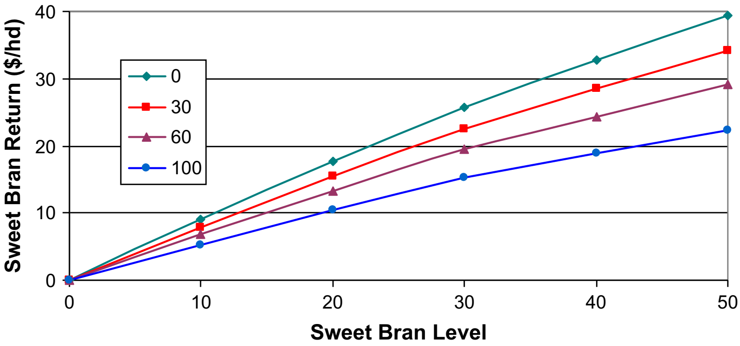


Fig. 15. Economic return from feeding Sweet Bran WCGF when fed at 0%, 10%, 20%, 30%, 40%, or 50% of diet DM at 0, 30, 60, or 100 miles from an ethanol plant.

feedlot size [44]. When the true fertilizer market value is placed on the manure, however, there is a net profit to manure management. Increases in dietary P level increase the fertilizer value of manure faster than the increase in cost of manure distribution. Accounting for the cost and fertilizer value of the manure, the profit per finished animal from manure management is about $4 per animal. When the WDGS manure management profit is added to the feeding profit from WDGS, the total WDGS profit per animal is $29 to $52 more than a conventional corn-fed animal. This accounting assumes that additional land is readily available on which to spread the manure. Accounting for the manure fertilizer value from DGS fed cattle can actually improve the profitability of cattle-feeding operations.

Wet distillers grains plus solubles storage

One problem that can be encountered is storage of wet feeds. WDGS has been successfully bagged if no pressure is applied to the bagger. Bags tend to settle because of the weight of the WDGS, resulting in low height and expanded width. Modified wet distillers grains (45% DM) and WCGF bag well, even with pressure.

Adams and colleagues [45] conducted two studies to determine methods to store WDGS (34% DM), because WDGS does not store in silo bags under pressure or pack into a bunker. The first study evaluated mixing WDGS with three different forage sources and mixing with DDGS or WCGF. The products were mixed in feed trucks and placed into 9-ft diameter silo bags. The bagger was set at a constant pressure of 300 psi. The height of the silo bag was a determining factor of storability. Inclusion levels of the feedstuffs were adjusted to improve the bag shape. The recommended levels of feedstuffs to incorporate (DM basis) when bagging WDGS are 15% grass hay, 22.5% alfalfa hay, 12.5% wheat straw, 50% DDGS, or 60% WCGF. The corresponding as-is percentages for these feedstuffs are

6.3%, 10.5%, 5.1%, 27.5%, and 53.7% of the mix, respectively. The second study was conducted by mixing grass hay with WDGS and storing in a concrete bunker. Both 30% and 40% mixtures of grass hay with WDGS (DM basis) packed well into the bunker. These values correspond to 14.0% and 20.1% of the as-is grass hay mix. In both experiments, the product was stored more than 45 days and the apparent quality did not change. Wet DGS can be stored in a silo bag or bunker silo when mixed with drier or bulkier feedstuffs. More information is available at http://beef.unl.edu.

Storage allows cattle feeders who have smaller numbers of animals to use wet byproducts and not have the products deteriorate with extended time between deliveries of fresh material from the plant. Wet byproducts are often more available and less expensive in the summer. Storage allows for purchase of wet byproducts in the summer and subsequent feeding in the winter.

The resulting stored (ensiled) mix of wheat straw and WDGS has also been fed to stocker calves. The palatability of the straw (cornstalks also) seems to have been enhanced by storage. The feeding value is at least equal to what would be expected from the mathematical blend of WDGS and wheat straw.

New ethanol industry byproducts

The evolving ethanol industry is continually striving to maximize ethanol production efficiency. Changes associated with this progress provide innovative byproduct feeds for producers to use that may be different nutritionally when fed to cattle. One example of a new byproduct feed is Dakota Bran Cake. Bran cake is a distillers byproduct feed produced as primarily corn bran plus distillers solubles produced from a prefractionation dry milling process. On a DM basis, bran cake contains less protein than WDGS and WCGF, similar NDF to both feeds, and similar to slightly less fat content as WDGS. Bremer and colleagues [46] evaluated Dakota Bran Cake in a finishing diet by comparing inclusion levels of 0%, 15%, 30%, and 45% of diet DM. Results indicated improved final weight, ADG, DMI, and F:G compared with feeding a blend of high-moisture and dry-rolled corn, suggesting this specific feed has 100% to 108% of the feeding value of corn. Buckner and colleagues [47] compared dried Dakota Bran Cake to DDGS supplementation in growing calf diets. Each of the two products was fed at 15% or 30% of the diet, replacing a 70:30 blend of brome grass hay and alfalfa haylage (DM basis). Animal performance improved as the inclusion of the byproducts increased. Dried DGS had improved performance compared with the dried Dakota Bran Cake at both inclusion levels. Dried Dakota Bran Cake had 84% the feeding value of DDGS with growing steers. Previous research has shown that DDGS has about 127% the feeding value of corn in forage-based diets. Dried Dakota Bran Cake therefore seems to have an energy value equal to 103% of corn. Dakota Bran Cake is only one example of how new ethanol industry byproducts feed relative to traditional finishing rations. Each new byproduct feed needs to be analyzed individually to determine the correct feeding value. Changes to plant production goals and production efficiency have a significant impact on the feeding value of byproducts produced.

Summary

Distillers grains, CGF, or a combination of both byproducts offer many feeding options to producers when included in feedlot diets. These byproduct feeds may effectively improve cattle performance and operation profitability. Wet DGS and WCGF have feeding values greater than DRC in beef finishing diets. Drying seems to reduce the feeding value of byproducts. The ability to keep cattle on feed and reduction in acidosis problems are likely responsible for the higher apparent feeding values and may be the primary advantages of using WDGS and WCGF in feedlot diets. Understanding and managing variations in fat and sulfur levels in DGS products may help optimize DGS inclusion in feedlot diets. It seems that WDGS feeds better with HMC and DRC than with SFC. With feedlot cattle, more intense corn processing may be optimal for diets containing WCGF. It seems that WCGF is a complementary feedstuff for diets containing WDGS, SFC, HMC, and DRC. The quality and quantity of roughages may be minimized in finishing diets containing byproducts. In the future, with increased supply of byproducts, feeding combinations of WDGS and WCGF may be advantageous. The high undegradable protein value of the distillers grains and WCGF make them excellent protein sources for young, rapidly growing cattle. Innovative ways of storing wet products offer opportunities for smaller producers to capture the value of byproduct feeds. New byproducts will be available in the future as the processes of making ethanol and other products from corn evolve. These new feeds should be evaluated with performance data to determine their respective feeding values.

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