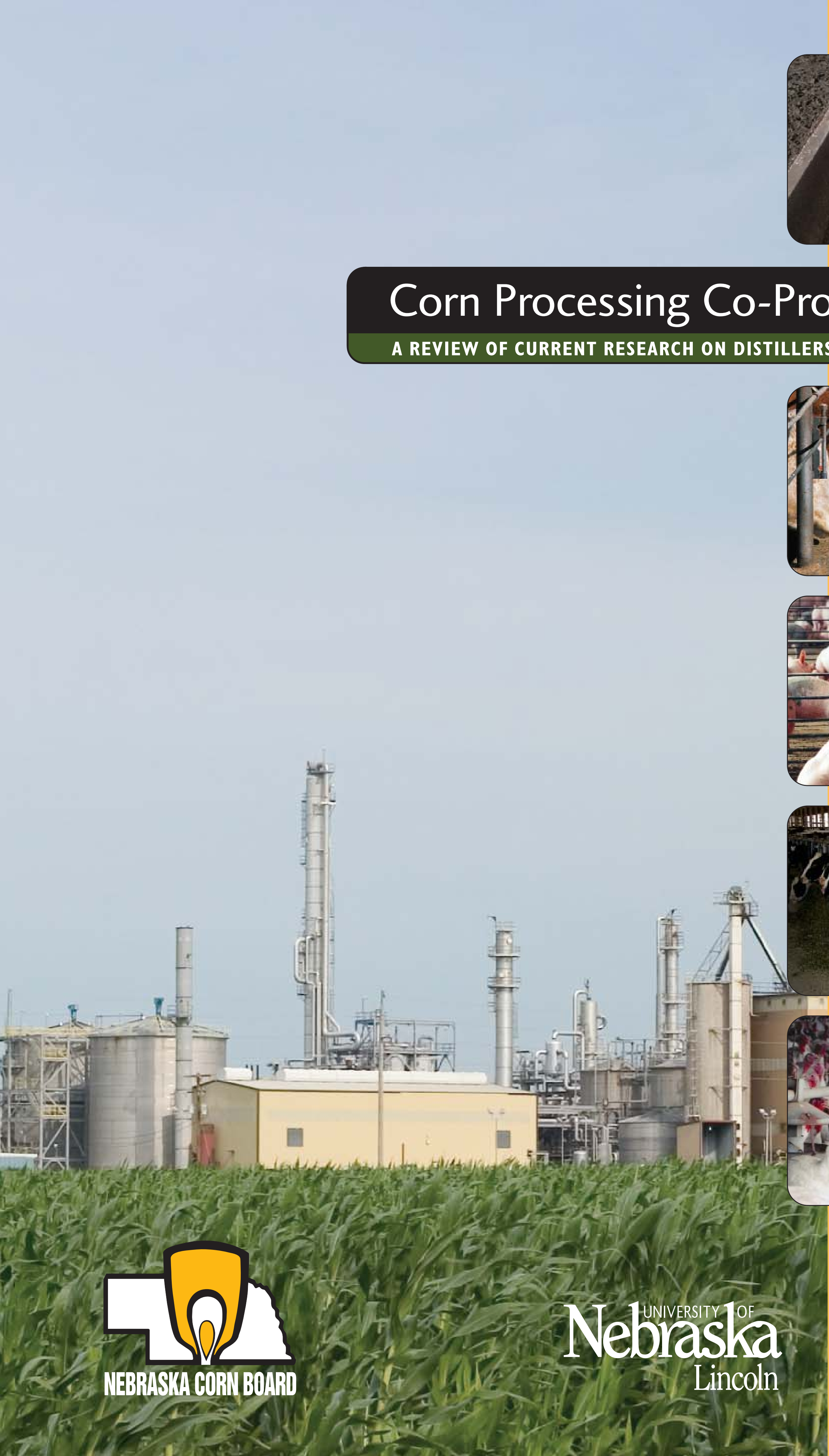

Corn Processing Co-Products Manual

A REVIEW OF CURRENT RESEARCH ON DISTILLERS GRAINS AND CORN GLUTEN

NEBRASKA CORN BOARD

UNIVERSITY OF Nebraska Lincoln

A joint project of the Nebraska Corn Board and the University of Nebraska–Lincoln Institute of Agriculture and Natural Resources

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Cooperative Extension Division

For more information or to request additional copies of this manual,
contact the Nebraska Corn Board at 1-800-632-6761 or e-mail k.brunkhorst@necorn.state.ne.us.

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TABLE OF CONTENTS

INTRODUCTION

Across the United States, ethanol production continues to expand with monthly production records being set. With the continued expansion in production, co-products have emerged as excellent feed sources for livestock.

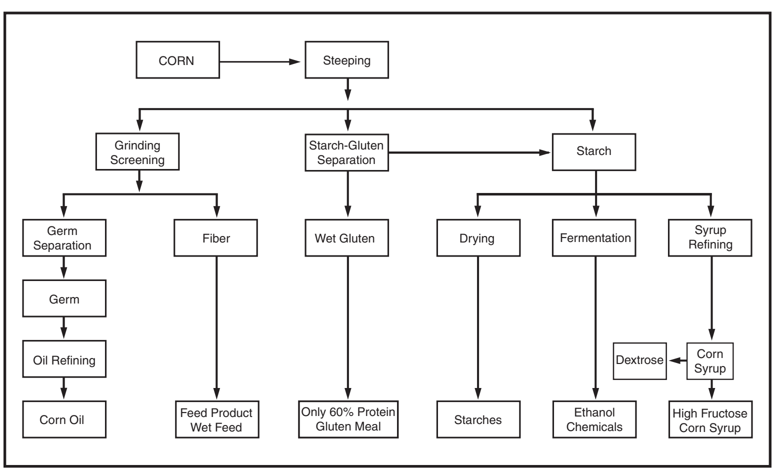
For purposes of this manual, co-products is defined as the feed product that remains following the wet mill or dry mill process. Research by various institutions and private companies continues to look at the characteristics and usages of co-products. This manual will provide you with an overview of research that has been completed, as well as a quick futuristic view of what may still need to be completed to help answer additional questions.

The production of ethanol is broken down into two main processes, the wet mill and dry mill. Each process produces different co-products.

The wet mill process starts with the corn kernel being soaked to soften the kernel. This is done to facilitate the separation of the various component parts, prior to it being processed into ethanol. From this wet mill process comes two feed co-products in corn gluten feed and corn gluten meal.

Shown below is a flow chart for the wet mill process.

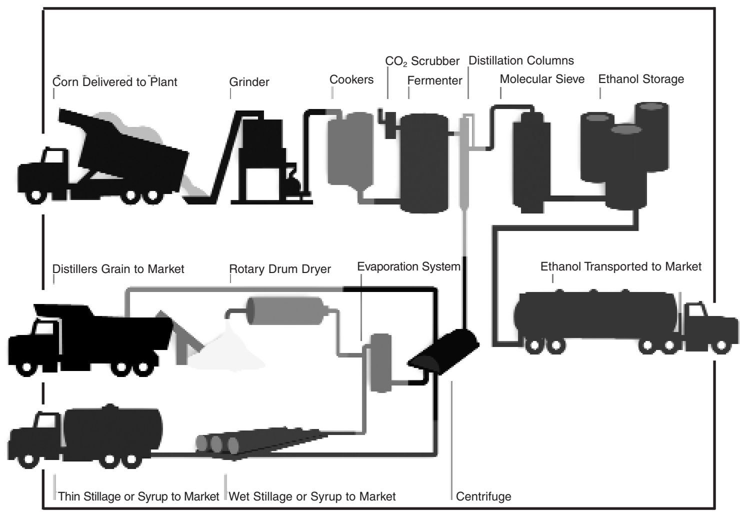
The Ethanol Production Process (Wet Mill)



In the dry mill process, the entire corn kernel is ground into a meal and then fermented into alcohol. From this process, one of the co-products is distillers wet grains, which can be dried.

Shown below is a flow chart for the dry mill process.

The Ethanol Production Process (Dry Mill)



On page 28 you will find definitions for the terms that are used in the research reviews of this manual.

We hope that you find this manual to be a valuable source of information on the usage and characteristics of the various co-products. Thanks to Dr. Galen Erickson, Dr. Phil Miller, Dr. Shelia Scheideler, and Dr. Paul Kononoff from the University of Nebraska-Lincoln, for assisting the Nebraska Corn Board in submitting the research reviews and giving their time and effort to this project.

GENERAL OVERVIEW OF FEEDING CORN MILLING CO-PRODUCTS TO BEEF CATTLE

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INTRODUCTION

Corn milling co-products are expected to increase dramatically in supply. Two primary types of milling processes currently exist, resulting in quite different feed products. The dry milling process produces distillers grains plus solubles, and the wet milling process produces corn gluten feed. These feeds can be marketed as wet feed, or they can be dried and marketed as either dry corn gluten feed or dry distillers grains with or without solubles. For the purposes of this article, only wet corn gluten feed (WCGF) and wet distillers grains plus solubles (WDGS) will be discussed. The majority of plant expansions are dry milling plants that produce WDGS; however, an increase in supply of WCGF is also expected. Therefore, these feeds may be very attractive for beef producers to use as an energy source. This article will focus on the production, composition of these feeds, energy values, and economics of using WDGS. Some other management issues will be discussed as well including grain processing when these co-products are used in feedlot diets, roughage level when these co-products are used, and feeding combinations of WDGS and WCGF. Forage fed situations will be covered with dried co-products as this will be the most common application for both energy and protein supplementation in many forage feeding situations.

WET MILLING

Wet milling is a process that requires use of high quality (No. 2 or better) corn that results in numerous products for human use. During this process (Figure 1), corn is "steeped" and the kernel components are separated into corn bran, starch, corn gluten meal (protein), germ, and soluble components. Wet corn gluten feed usually consists of corn bran and steep, with 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 (1992). Dry corn gluten feed contains less energy than wet corn gluten feed (Ham et al., 1995) when fed at high levels in finishing diets. Wet corn gluten feed can vary depending on the plant capabilities. Steep liquor contains more energy and protein than corn bran or germ meal (Scott et al., 1997). Therefore, plants that apply more steep to corn bran or germ meal will produce WCGF that is higher in CP and energy.

WCGF contains 16 to 23% CP, which is approximately 80% ruminally degradable (degradable intake protein, DIP) protein used by microbes. During wet milling, corn gluten meal is removed and marketed in higher value markets. Corn gluten meal should not be confused with WCGF, as corn gluten meal contains approximately 60% CP which is only 40% DIP or 60% bypass protein (undegradable intake protein, UIP). Distinct differences exist for WCGF, even within companies, due to plant-to-plant variation. Stock et al., (1999) divided WCGF into two main categories, depending on the ratio of steep to bran. Because of differences in the amount of steep added, WCGF has approximately 101 to 115% the energy value of dry-rolled corn when fed at levels of 20 to 60% of diet DM (Stock et al., 1999). Higher energy (and protein) is associated with increases in steep added in WCGF.

DRY MILLING

In the dry milling industry, the feed product(s) that are produced are distillers grains, distillers grains + solubles, and distillers solubles. Depending on the plant and whether it is producing wet or dry feed, the relative amounts of distillers grains and distillers solubles mixed together varies. However, our current estimates are that wet distillers grains + solubles are approximately 65% distillers grains and 35% distillers solubles (DM basis). Distillers grains

Figure 1 – Schematic of the wet milling industry resulting in wet or dry corn gluten feed.

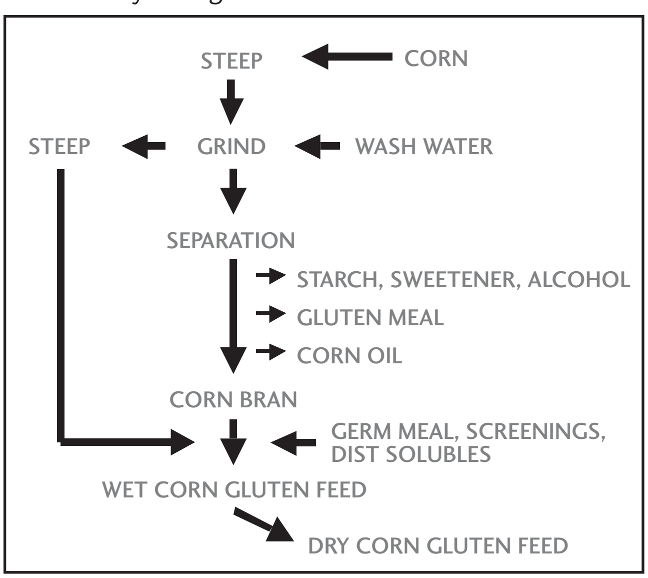


Figure 2 – Schematic of the dry milling industry with the feed products produced.

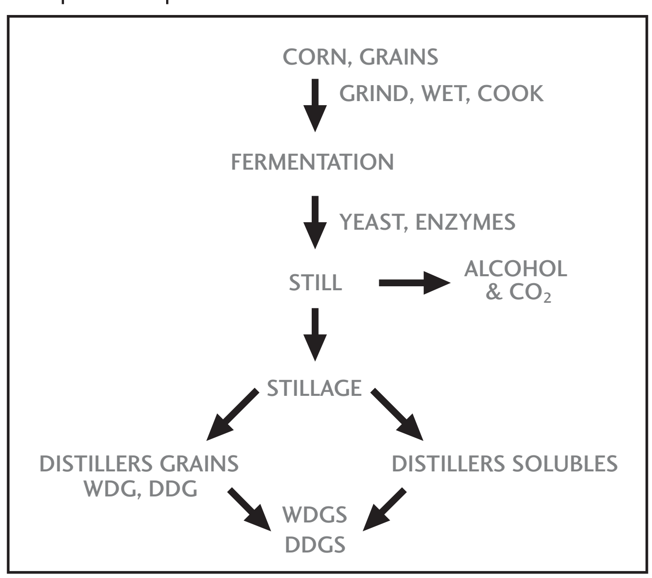


Table 1 – Energy value of wet vs dry grains

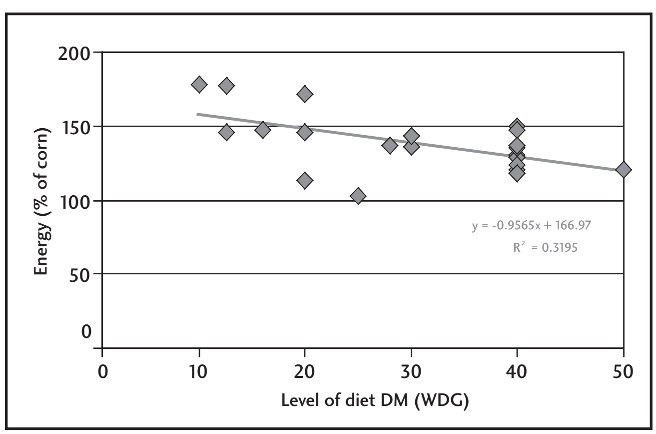
	Control	Wet	Low[a]	Medium[a]	High[a]
Daily feed, lb	24.2 b[bc]	23.56[b]	25.3[c]	25.0[a]	25.9[a]
Daily gain, lb	3.23[b]	3.71[c]	3.66[c]	3.71[c]	3.76[c]
Feed/gain	7.69[b]	6.33[c]	6.94[d]	6.76[d]	6.90[d]
Improvement:					
Diet	--	21.5	…………11.9 (ave.)……..…..		
Distillers vs corn	--	53.8	…………….29.8…………….		

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

(+ solubles) will hereby be referred to as either WDGS (wet distillers grains) or DDGS (dry distillers grains). Our assumption is that the distillers grains will contain some solubles, but this can vary from plant to plant. The dry milling ethanol process (Figure 2) is relatively simple where corn (or another starch source) is ground, fermented, and the starch converted to ethanol and CO_2. Approximately 1/3 of the DM remains as the feed product following starch fermentation assuming that starch source is approximately 2/3 starch. As a result, all the nutrients are concentrated 3-fold because most grains contain approximately 2/3 starch. For example, if corn is 4% oil, the WDGS or DDGS will contain approximately 12% oil. The wet milling industry is more complex and the corn kernel is divided into more components for higher value marketing. For example, the oil is extracted and sold in the wet milling industry as is the corn gluten meal, 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 process is that the resulting feed products from these two industries are quite different based on how they are produced.

The majority of the research on distillers grains as an energy source has been conducted on finishing cattle. Feeding wet distillers grains (WDGS) results in better performance than dry distillers grains (DDGS; Table 1). Experiments evaluating the use of wet distillers co-products in ruminant diets are available (DeHaan et al, 1982; Farlin, 1981; Firkins et al., 1985; Fanning et al., 1999; Larson et al., 1993; Trenkle, 1997a; Trenkle, 1997b; Vander Pol et al., 2005a). In the experiments with finishing cattle, the replacement of corn grain with wet distillers co-product consistently improved feed efficiency. Figure 1 summarizes these studies conducted on wet distillers grains with energy value expressed relative to corn. The energy value is consistently higher than corn. These experiments suggest a 15 to 25% improvement in feed efficiency when 30 to 40% of the corn grain is replaced with wet distillers co-product. The energy value at medium levels (12 to 28%, average of 17% of diet DM) is approximately 140 to 150% the energy of corn. When higher levels are used (average of 40%), the energy was 130% that of corn. The optimum

Figure 3 – Energy content of wet distillers grains plus solubles when replacing corn at different inclusions.



level for feedlot producers to use is 30 to 40% of diet DM when plants are within 30 miles of the ethanol plant (Vander Pol et al., 2005a, 2005b). As the distance increases from the plant to the feedlot, the optimum inclusion of WDGS decreases to 20 to 30%. This comparison suggests that more WDGS can be fed; however, the optimum inclusion is dependent on more than just the energy value of WDGS.

COMPOSITION

Table 2 contains data on plant averages and some indication of variation for various corn milling co-products. Variation exists from plant to plant and within a plant. These table values should not replace sampling and analysis of feed from individual plants. The dry distillers grains plus solubles (DDGS), WDGS, and condensed corn distillers solubles (CCDS) are all from one plant in Nebraska and represent average values for 2003. The standard deviations are for composite weekly samples, not for load variation, which is not indicative of actual variation observed at a feedlot and may reduce variation by infrequent sampling. The plant with an excellent database on variability is the Cargill Blair facility. The standard deviation is low on DM change from load to load. This relates to two things: process development to minimize variation and culture of those operating the plants to minimize variation in feed products. The coefficient of variation (CV, %) can be calculated as: (standard deviation/average) x 100. The energy values used in Table 3 are based on performance data summarized in this paper and other reviews. In another recent review of composition and variation in plants and across plants, the reader is referred to Holt and Pritchard (2004). Moisture and DM variation are probably of greatest importance with wet co-products. However, both fat and S can vary in wet distillers grains which could lead to changes in energy value and potential for toxicity, respectively.

Table 2. Nutrient composition of selected corn milling co-products.

Feedstuff:[a]	DRC[b]	WCGF-A	WCGF-B	DDGS[c]	WDGS[c]	CCDS[c]	MWDGS	steep[d]
DM	90.0	44.7	60.0	90.4	34.9	35.5	45-50	49.4(49.0)[e]
SD	0.88	0.89	0.05	1.7	3.6	1.4	NA	1.0(0.58)[e]
CP, % of DM	9.8	19.5	24.0	33.9	31.0	23.8	NA	35.1
SD	1.1	0.63	0.51	1.3	0.9	1.5	NA	1.1
UIP, % of CP	60.0	20.0	20.0	65.0	65.0	65.0	NA	20.0
P, % of DM	0.32	0.66	0.99	0.51	0.84	1.72	NA	1.92
SD	0.04	0.03	0.04	0.08	0.06	0.27	NA	0.11
TDN, %	90.0	90.0	94.5	101	112	112	NA	113
NEg, Mcal/lb	0.70	0.71	0.80	0.78	0.87	0.87	NA	0.88

[a] DRC=dry rolled corn with NRC (1996) values, WCGF=wet corn gluten feed from two plants, DDGS=dried distillers grains + solubles, WDGS=wet distillers grains + solubles, CCDS=condensed corn distillers solubles (corn syrup), MWDGS=modified wet distillers grains + solubles, steep is steep liquor from wet milling plants.

[b] DRC values based on NRC (1996) values with approximately 3500 samples

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

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

[e] Values in parentheses are monthly composites for 2003 from one plant in Nebraska, with assumptions that it is a mixture of steep and distillers solubles.

Table 3. Wet or dry corn gluten feed or corn in forage based diets for growing calves[a].

	Forage	Corn	DCGF	WCGF
DMI, lb/d	11.7	18.0	16.4	16.2
ADG, lb	1.16	2.25	2.15	2.36
Feed/gain	10.5	8.01	7.64	6.86

[a]Balanced for 11.5% CP.

Table 4. Escape Protein Values

Source	% protein escape
Soybean meal	30
Wet distillers grains	60-70
Dried distillers grains	60-70
Distillers solubles	30

USE IN FORAGE DIETS

Beef calves from weaning until they enter feedlots, developing heifers and beef cows are fed primarily forage diets. Especially in the winter, forages are low in protein and phosphorus and need to be supplemented. Corn gluten feed contains highly digestible fiber and degradable protein which are good sources of energy and protein for rumen microbes, especially in forage-based diets (DeHaan et al., 1983). Wet and dry corn gluten feed were compared to dry-rolled corn for growing calves fed grass hay, wheat straw, and corn stalklage. The gluten feed or corn replaced 40% of the forage (Oliveros et al., 1987). The supplements nearly doubled gains and improved feed conversion (Table 3). Wet and dry gluten feeds had better feed conversions than corn and WCGF had better feed conversion than DCGF. The apparent energy value of DCGF was 10% greater than corn, while WCGF was 31% higher than DCGF and 42% greater than corn in these forage-based diets.

Clearly, gluten feed is an excellent source of nutrients for forage-based diets. There is little to no starch in gluten feed, which results in no negative effect on fiber digestion. The DIP in gluten feed is an excellent source of protein for microbes. Protein in forages is highly degraded in the rumen. In certain production situations, cattle may need to be supplemented with undegraded (UIP; bypass) protein to meet metabolizable protein (MP) requirements. Distillers grains (wet or dry) are an excellent source of undegraded protein and phosphorus. The values obtained from feeding trials for undegraded protein are shown in Table 4. Wet grains were compared to dry grains and the value of the protein was similar. This suggests that the high escape protein value of distillers grains is due to the innate characteristics of the protein and not to drying or moisture content, and does not appear to be influenced by acid-detergent insoluble protein (ADIN) which is a common measure of heat damaged protein.

Stocker calves, developing heifers and cows may need energy supplementation in addition to supplemental protein and phosphorus. It is advantageous if the same commodity can be used for supplemental energy as well as protein. We previously stated that distillers grains should have 120% the energy value of corn grain. Additional advantages for distillers grains are that it contains very little starch and therefore should not depress fiber digestion.

During drought conditions these co-products may be very competitive as energy supplements for use by ranchers. When forage quality is poor (winter) or quantity is limiting (drought), co-products may fit. Research has been initiated at the University of Nebraska-Lincoln to address the usefulness and value of dry co-products in cow-calf situations. Loy et al., (2004) concluded that DCGF decreases feed costs compared to conventional hay feeding when fed over the winter for developing heifers on a commercial, Nebraska ranch in the sandhills. In their study, a treatment system (TRT) was compared to their conventional management using over 550 heifers in each group across two years. The TRT system utilized only grazed winter forage and DCGF supplementation compared to some winter grazing, with hay and protein supplementation. Performance differences are presented in Table 5; however, little differences were observed in developing heifer performance by design. The major implication was reduced costs ($6.71 per heifer) through the winter while maintaining excellent performance and reproduction.

Table 5. Weight, body condition, and conception rates of heifers in two systems, CON which were fed hay with supplement and TRT which used increasing amounts of corn gluten feed along with grazed winter forage.

Item	CON	TRT
Year One		
Pre-calving BW change, lb	100.0	98.3
Pre-calving BCS change	-0.16[a]	-0.08[b]
Post-calving BW change, lb	-100.1	-98.3
Post-calving BCS change	0.16	0.28
Year Two		
Pre-calving BW change, lb	-5.1[a]	12.3[b]
Pre-calving BCS change	-0.75[a]	-0.48[b]
Post-calving BW change, lb	2.82	0.04
Post-calving BCS change	-0.30[a]	-0.57[b]
Pregnancy rate, %e	96.1	96.4

[a,b] Unlike superscripts within a row differ, P < 0.05.
[c,d] Unlike superscripts within a row differ, P < 0.10.
[e] Percentage pregnant with second calf. P-value reflects chi square analysis.

A similar experiment was conducted using DDGS (Stalker et al., 2006). Because of the higher energy content of DDGS, a smaller amount was needed to meet protein and energy requirements of these bred heifers (1353 heifers were used). Feeding DDGS and grazing winter range with heifers led to slightly better winter gains and changes in body condition compared to the hay-fed, control heifers. Pregnancy rates were 97% for both treatments. Most important, $10.47 per heifer was saved in feed costs by using DDGS and winter range versus a conventional system of hay, supplement, and range.

An experiment was conducted with 120 crossbred heifers to determine the value of dry distillers grains (DDGS) in high-forage diets, and to evaluate the effect of supplementing daily compared to three times weekly (Loy et al., 2003). Heifers were fed to consume grass hay ad libitum and supplemented with DDGS or dry rolled corn (DRC). Supplements were fed at two levels, and offered either daily or three times per week in equal proportions. Heifers supplemented daily ate more hay, gained faster (1.37 vs. 1.24 lb per day), but were not more efficient than those supplemented on alternate days (Table 6). At both levels of gain, DDGS heifers gained more and were more efficient than DRC fed heifers. The calculated net energy values for DDGS were 27% greater than for DRC.

Table 6. Growing calf performance over 84 days when fed native grass hay (CP = 8.7%) supplemented with either corn or DDG for two levels of gain. Net energy was 27% greater for DDG compared to corn (Loy et al., 2003).

		Low[a]	High[a]
ADG, lb/d	Corn	.81 ± .06	1.57 ± .05
	DDGS	.99 ± .05	1.89 ± .05
Feed conversion	Corn	15.9 ± .5	9.8 ± .5
(DMI/ADG)	DDGS	12.8 ± .5	8.0 ± .5

[a]LOW = supplement fed at 0.21% BW, HIGH = supplement fed at 0.81% BW.
[b]DDGS = dry distillers grains; DRC = dry rolled corn

The last area where co-products may fit in forage situations is with grazing corn residues. Incremental levels of WCGF were fed to calves grazing corn residues. Based on statistical and economical analysis of the data collected, feeding wet corn gluten feed (5.0-6.5 lb/ head/day; DM basis) will increase stocking rate on corn residue and reduce winter costs by 11%. Given that 3.5 lb DM/day wet corn gluten feed will meet the protein and phosphorus needs of calves, and feeding above 6.0 lb/d will not increase gains, wet corn gluten feed should be fed at 3.5-6.0 lb DM/day, producing gains from 1.28-1.88 lb/day (Jordon et al., 2001). In a similarly designed study using DDGS, Gustad et al. (2006) fed 1.5, 2.5, 3.5, 4.5, 5.5, and 6.5 lb/steer/d to calves grazing corn residue. Gains increased quadratically ($P < 0.01$) with ADG ranging from 0.90 to 1.81 lb.

CORN PROCESSING

Feeding corn milling co-products in feedlot diets reduces acidosis-related challenges from starch fed to ruminants. Both WCGF and WDGS have little to no starch remaining following the milling process. Therefore, feeding these co-products will dilute the starch that is fed and may influence rumen metabolism. Krehbiel et al., (1995) observed a decrease in subacute acidosis when WCGF was fed to metabolism steers. In many experiments, feeding WCGF results in increased DMI, which would be considered a symptom often observed with subacute acidosis.

Because processing corn increases rate of digestion by microbes, rumen acid production is increased and the risk of acidosis is increased (Stock and Britton, 1993). Feeding wet corn gluten feed (WCGF) helps prevent the risk of acidosis with high-grain diets (Krehbiel et al., 1995). Numerous studies have been conducted at the University of Nebraska-Lincoln to determine if energy values are markedly improved in diets containing WCGF when corn is more intensely processed. Scott et al. (2003) evaluated various corn processing techniques and observed improved feed conversions as processing intensity increased when feeding calves or yearlings (Table 7). Macken et al. (2006) fed DRC, FGC, SFC, and HMC processed as rolled (roller mill) and ground (tub grinder) to calves with all diets containing 25% WCGF. Whole corn was not fed in this study, but processing corn more intensely significantly improved performance.

Apparently, HMC appears to have greater energy value when diets contain WCGF than what was previously observed (diets not containing WCGF). Our conclusion is that intense processing has tremendous value in diets containing WCGF.

However, corn processing in diets containing WDGS appears to be somewhat different than diets containing WCGF. Vander Pol et al., (2006) fed diets containing either

Table 7. Effect of corn processing when fed with wet corn gluten feed (Macken et al., 2006; Scott et al., 2003).

25% WCGF (Macken et al., 2006)	Processing method[a]				
	DRC	FGC	RHMC	GHMC	SFC
ADG, lb	4.23	4.35	4.21	4.24	4.33
Feed:gain ratio, DM	5.49[b]	5.29[c]	5.13[d]	5.05[d]	4.91[e]
NEg (corn), Mcal/cwt	70.0	73.4	76.4	77.7	80.4
Fecal starch, %	19.2[b]	11.8[c]	10.6[cd]	8.4[d]	4.1[e]

32% WCGF with calves (Scott et al., 2003)	Processing method[a]				
	Whole	DRC	FGC	RHMC	SFC
ADG, lb	4.18	4.24	4.17	4.15	4.25
Feed:gain ratio, DM	5.92[b]	5.52[c]	5.32[d]	5.26[de]	5.18[e]

22% WCGF with yearlings (Scott et al., 2003)	Processing method[a]			
	DRC	FRC	RHMC	SFC
ADG, lb	3.98[b]	3.95[b]	4.02[b]	4.22[c]
Feed:gain ratio, DM	6.09[bc]	6.15[b]	5.97[c]	5.54[d]

[a]DRC = dry rolled corn, FGC = fine ground corn, FRC = fine rolled corn, RHMC = rolled high moisture corn, GHMC = ground high moisture corn, SFC = steam flaked corn, whole = whole corn.
[b,c,d,e] Means with different superscripts differ ($P < 0.05$).

whole, DRC, HMC, a 50:50 blend of HMC and DRC (DM basis), SFC, or FGC to calf-feds for 168 days. Cattle fed DRC, HMC, or a combination of HMC and DRC gained more and were more efficient (lower feed conversion) than cattle fed whole corn. Interestingly, cattle fed steam-flaked corn and finely ground corn were not as efficient. It is unclear why more intense processing did not respond when diets contained WDGS similar to diets containing WCGF. More work is in progress to address the optimum corn processing method with diets containing WDGS.

COMBINATIONS OF CO-PRODUCTS

With the large expansion of ethanol plants in the Midwest, an option for many feedlots will be utilizing both WDGS and WCGF at the same time. In addition to their commercial availability, another reason for feeding a combination of WDGS and WCGF is due to their nutritional profiles. Synergistic effects in feeding a combination of these co-products may be observed because of differences in fat, effective fiber, and protein components. Loza et al., (2004) fed yearling steers a 50:50 blend of WDGS and WCGF (DM basis) at inclusion levels ranging from 0 to 75% DM. This experiment also evaluated different forage levels. A level of 7.5% alfalfa hay was used across all the treatments, and a lower alfalfa level was included in each of the co-product diets, decreasing the forage inclusion as the rate of inclusion of co-products in the diets increased (i.e. 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 co-product blend level. The lack of differences in performance with decreasing forage would indicate that the co-product inclusion was enough to prevent the negative consequences of sub-acute acidosis (Table 8). The analysis of the pooled data from each co-product level indicated that the performance of the steers fed the maximum co-product level (75%), regardless of the forage level, was not different than a typical corn based diet (0% co-product blend). However, the diets including a 25 and 50% blend of WDGS and WCGF resulted in significantly better animal performances than the control. In conclusion, it is feasible to decrease the forage levels with high inclusion of co-products. Producers may also feed levels as high as 75% without negatively affecting performance. However, optimum inclusion rates of a co-product blend would be between 25 and 50% DM.

Feeding a combination of WDGS and WCGF also offers producers greater flexibility. A major challenge facing some ethanol plants is not having feed for cattle feeders on a consistent basis. Cattle do not respond well if either WDGS or WCGF, as sole co-products in the diet, are removed and replaced with corn abruptly. Therefore, one approach would be to feed a combination to ensure that at least one co-product is consistently in the ration.

NEW ETHANOL INDUSTRY CO-PRODUCTS

The evolving ethanol industry is continually striving to maximize ethanol production efficiency. Changes associated with this progress will provide innovative new

Table 8. Effect of different inclusion levels of a 50:50 blend of WCGF and WDGS (DM basis) and forage levels fed to yearling steers.

Blend:	0%DM	25% DM		50% DM		75% DM	
Alfalfa:	7.5	5	7.5	2.5	7.5	0	7.5
DMI, lb/day	24.3[a]	26.3[bc]	26.5[b]	25.4[c]	26.1[bc]	23.0[d]	23.6[ad]
ADG, lb/day	3.99[a]	4.70[b]	4.57[b]	4.55[b]	4.56[b]	3.86[a]	3.93[a]
F/G	6.10[a]	5.60[c]	5.80[bc]	5.59[c]	5.73[bc]	5.97[ab]	6.01[ab]

[a,b,c,d] Means with different superscripts differ (P<0.05). All diets contain a 50:50 DRC- HMC blend and 5% supplement.

co-product feeds for producers to utilize that may be quite different nutritionally when fed to cattle. One example of a new co-product feed is Dakota Bran Cake. Bran cake is a distillers co-product feed produced as primarily corn bran plus distillers solubles produced from a hybrid wet and 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. A study by Bremer et al., (2005) evaluated Dakota Bran Cake inclusion up to 45% DM by comparing 0, 15, 30, and 45% of diet DM. Results indicated improved final weight, ADG, DMI and F:G compared to feeding a blend of high-moisture and dry-rolled corn, suggesting this specific feed has 100 – 108% of the energy value of corn. Dakota Bran Cake is only one example of how new ethanol industry co-products will feed relative to traditional finishing rations. Each new co-product feed needs to be analyzed individually for correct feeding value. Changes to plant production goals and production efficiency have a significant impact on the feeding value of co-products produced.

CONCLUSIONS

Distillers grains have 120 to 150% the energy value of dry rolled corn in beef finishing diets and wet corn gluten feed has 100 to 110% the energy value depending on steep level in gluten feed. Dry co-products have less energy. These co-products also work very well in forage feeding situations as both protein supplements but also as an energy supplement or forage replacement (particularly high quality forages).

With feedlot cattle, more intense corn processing may be optimal for diets containing WCGF. It appears that with diets containing WDGS, high-moisture corn and dry-rolled corn work well. In the future, with increased supply of co-products, feeding combinations of WDGS and WCGF may be advantageous. It also appears that many new co-products 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 how the new co-products will feed.

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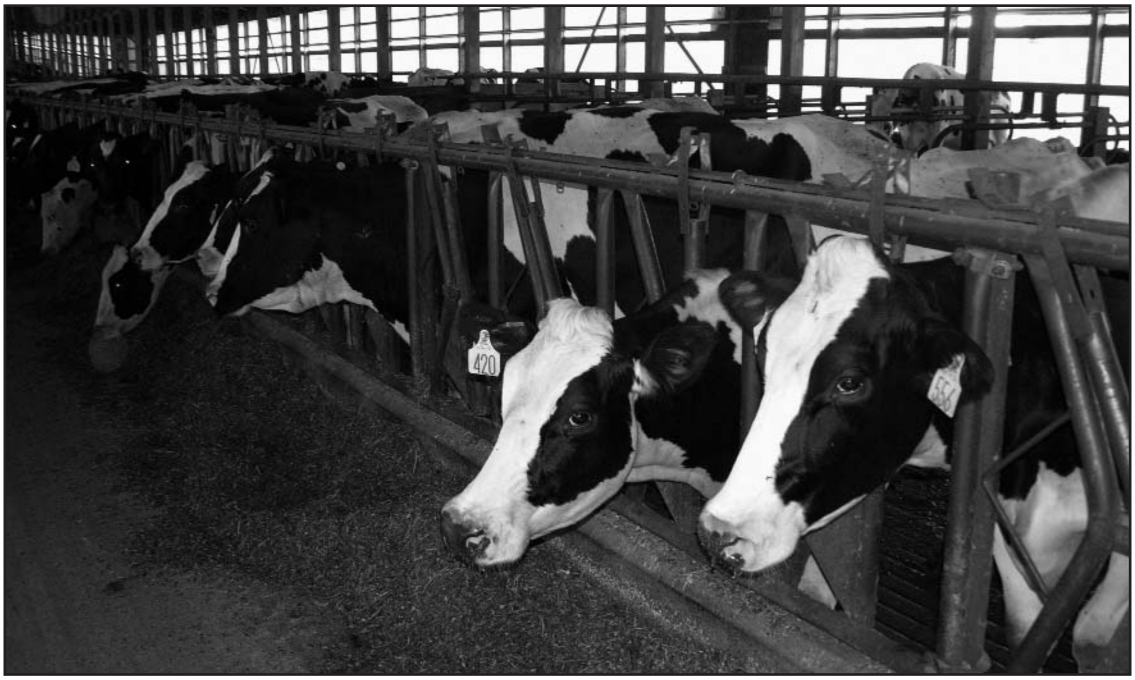

FEEDING DISTILLERS GRAINS TO DAIRY CATTLE

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INTRODUCTION

The production of ethanol from corn grain has become an effective strategy to produce high quality and clean liquid transportation fuels. In fact, the growth of the U.S ethanol industry has provided an economic stimulus for U.S.-based agriculture. The feed industry plays an integral role in the ethanol production industry. For example, the primary product of the dry milling production process is ethanol; but approximately one-third of the total dry matter is recovered in the form of co-products. The supply of these co-products continues to grow at a rapid rate. As a result co-products are becoming an increasingly available feedstuff that are usually an extremely cost effective feed ingredient for lactating dairy cattle.

In the dry milling process, either corn or sorghum is cleaned, ground dry and the whole kernel is used in the fermentation process to produce ethanol and carbon dioxide. In this case there are basically two products of interest. The first product is the solid, unfermented grain portion called wet distillers grains (WDG) and second is the thin stillage fraction that contains water, small particles, yeast and all other soluble nutrients. If not sold as WDG, material may be further dried yielding dried distillers grains (DDG); and in some cases the thin stillage is added back to yield dried distillers plus solubles (DDGS). Table 1 lists the estimated nutrient content of corn distillers grains (CDG) and other common feeds.

NUTRIENT COMPOSITION OF DISTILLERS GRAINS

PROTEIN

Protein contained in the feed can be utilized by rumen microbes. However, the rumen undegradable protein (RUP) portion may by-pass the rumen and supply the small intestine with protein where it is digested and absorbed. On a dry matter basis, corn distillers grains contain approximately 30% crude protein, commonly ranging between 25 and 35%. Corn distillers grains are a good source of rumen undegradable protein (approximately 50%), with wet being slightly higher than dry.

Our growing understanding of protein nutrition and utilization has lead us to consider the use and supply of individual amino acids (AA) during ration balancing procedures. Limiting AA are defined as those amino acids that are in shortest supply (Socha et al., 2005). The NRC (2001) suggests methionine (MET) is most limiting in rations that depend upon soy or animal protein for major RUP supply. In rations that are formulated to contain high amounts of corn products, the supply of lysine (LYS) is believed to be more limiting (Liu, et al., 2000). In diets containing 20 % CDG, the supplementation of ruminally protected lysine and methionine results in an increase in milk protein percent and yield (Nickols et al., 1998), but this has not been observed in all studies (Liu et al., 2000). When balancing diets containing high levels of CDG, nutritionists should evaluate the proportion of predicted lysine and methinone in the metabolizable protein (MP) fraction. More specifically, nutritionists should strive for a lysine to methionine ratio (LYS:MET) of 3.0:1.0. Although in most situations, this bench-mark may be difficult to reach, nutritionists may improve the amino acid profile of the ration by increasing the inclusion rate of high-LYS protein supplements such as fish meal or soy-products.

ENERGY AND EFFECTIVE FIBER

Although field nutritionists often view CDG as a useful protein or nitrogen source, this feedstuff contains more than simply nitrogen. Feeding distillers grains in replacement of corn grain is useful in providing energy in the form of fermentable fiber. Because fiber is digested at a slower rate than other forms of energy such as starch, feeding CDG to ruminants may be useful in reducing the incidence of rumen acidosis (Klopfenstein et al., 2001). Distillers grains typically contain 34% neutral detergent fiber (NDF) and 13% fat on dry matter basis. Energy requirements for maintenance and milk production are expressed in net energy for lactation (NEL) units. The current NRC (2001) publication outlining the nutrient requirements for dairy cattle calculates an NEL value on the total diet. Even though the energetic contribution of individual feeds is a function of other feeds included in the diet, there is interest in knowing the baseline NEL value of individual feeds because most formulation programs require NEL as a nutrient input. The energy content of CDG, when replacing corn and soy bean meal, has recently been evaluated (Birkelo et al., 2004). This research suggests that the NEL value for wet CDG is 1.03 Mcal/lb and is 10-15% higher than the current NRC listing. This and other research supports the suggestion that CDG is an excellent ruminant feed and that the digestible fiber portion of this feedstuff is a valuable source of energy. Nutritionists should be reminded that the NEL -value of CDG may be variable and depend on several factors including the chemical composition and the digestibility of the feed itself (most notably NDF and fat), the level of intake and the nature of other ingredients fed to the animal.

Effective fiber is the portion of the diet that is believed to stimulate rumination, chewing activity and saliva secretion, all which is designed to help to maintain healthy rumen function and normal pH levels. Nutritionists are often concerned about rumen pH because when pH levels fall below 6.0, fiber digestion may be impeded and milk fat levels may become depressed (Russell and Wilson, 1996). It is believed that rumen pH is a function of lactic acid and VFA production and is buffered by saliva (Maekawa et al., 2002). Because of this finding, it is a common practice to feed diets of longer particle size, therefore a greater amount of effective fiber, so that saliva production is stimulated. In support of this hypothesis, Krause et al. (2002) noted that the intake of particles > 19.0-mm was negatively correlated with the amount of time rumen pH was below 5.8. However, it is also known that diets should not be excessively long or coarse as they are more difficult to mix and may induce cattle to sort out ration ingredients (Kononoff et al., 2003). When CDG are used to substitute forage in the TMR, chewing activity is believed to be reduced due to the finer particle size. Nutritionists should not necessarily use this logic to infer that feeding CDG will result in lower rumen pH. In fact it is likely that diets may be balanced so that the inclusion of CDG will not influence rumen pH. When evaluating a diet to determine a possible risk of subclinical acidosis, it is important to also consider levels of fiber and non-structural carbohydrates, along with their associated fermentability (Yang et al., 2001). Using the Penn State Particle Separator, at least 5-10% of the particles should be at least three quarters of an inch long and the diet should contain 26-30% NDF.

PHOSPHORUS AND SULFUR

The mineral content of feeds and the associated levels in livestock manure has received considerable attention. When including CDG into dairy diets producers should understand that although they contain many valuable nutrients, these feeds may also contain high levels of both phosphorus and sulfur. Although it is unlikely that these levels would contribute to the loss of any milk production or health problems, producers should be mindful of the importance of dealing with these minerals. Recently, the land application of dairy manure has risen to national attention and continues to face growing scrutiny because manure may accumulate minerals and has the potential to contaminate surface and groundwater. To avoid these problems, producers should ensure that their waste management plan attempts to avoid excessive accumulation of minerals and allows for maximum crop use of the nutrients contained in the manure.

WET VERSUS DRY …
PRACTICAL CONSIDERATIONS

As mentioned above, distillers grains may be available in either a wet or dry form and the nutrient content, when expressed on a dry matter basis, is similar for both. One possible major difference between CDG of these forms may be the fact that the RUP portion may be higher for CDG in the dry form (Firkins et al., 1984). Although it is generally believed that there is little difference in milk production when animals are fed either form, beef feedlot studies have demonstrated that rations containing wet distillers grains are consumed in lower amounts and result in greater feed efficiencies than those containing dried distillers grains (Ham et al., 1994). Unfortunately less research has investigated possible differences in milk performances. In one study in which lactating dairy cattle were fed diets containing 15% (DM basis) of either wet or dry CDG no differences were observed in milk production, composition, fiber digestibility, and efficiency of milk production (Al-Suwaiegh et al., 2002).

When deciding which form may fit best, producers should evaluate several factors including distance from plant of origin, the anticipated feeding rate, the on-farm storage facilities and handling equipment. Because a wet product may not be stored as long and is usually associated with high shipping charges, dried forms may be most feasible if a plant is not located near the farm. However, this also increases the price of the feedstuff. If the farm is located near a plant, wet forms may be cost effective, but producers should be mindful of the fact that the rate of spoiling is also dependent upon the feeding rate and environmental temperature. Generally speaking, wet loads should arrive at least weekly to ensure the pile is "fresh." There continues to be interest in ensiling feeds such as wet distillers grains as a method to eliminate oxygen exposure and ultimately reduce feed spoiling and loss. Additionally, a number of commercial direct application preservative products may be useful in extending shelf life of these feeds, but producers should be mindful of these added costs.

Table 1. Chemical composition of corn gluten feed, distillers grains, corn silage, alfalfa haylage, and soybean meal.

	Dry Corn Gluten Feed	Dry Distillers Grains	Corn Silage	Alfalfa Silage	Ground Corn	Soybean Meal
Dry Matter, %	89	88	34	40	88	90
Crude Protein, % DM	25	31	8	21	9	50
Rumen Undegradable Protein, % CP	30	50	35	20	43	43
Fat, % DM	3	13	3	4	4	4
Acid Detergent Fiber, % DM	12	17	26	35	3	8
Neutral Detergent Fiber, % DM	37	34	44	44	10	13
Lignin, % DM	1.6	5	3.5	8	1	1
Starch, % DM	15	5	31	2.5	69	1.7
Calcium, % DM	0.13	0.09	0.27	1.4	0.04	0.43
Phosphorus, % DM	1.1	0.91	0.24	0.33	0.30	0.74
Sulfur, % DM	0.50	0.63	0.10	0.25	0.10	0.39

CONSIDERATIONS FOR FEEDING

NUTRIENT VARIATION

Recent investigations conducted at the University of Minnesota (Knott et al., 2004) has demonstrated that there may be a high degree of variation in the nutrient content of co-products, such as distillers grains, both within and across production plants. For example, these investigators demonstrated that the crude protein level in distillers grains may range from 25 - 35%, with variation also observed in fat (10-12%), NDF (8-10) and phosphorus (0.8-1%). These investigators note that one of the greatest sources of nutrient variation for DDGS depends on the amount of solubles that were added to the grains. Along with the concentration of CP, the availability of these nutrients may also vary. Hence researchers are beginning to direct their attention towards creating practical methods for controlling this variation. Research from The Ohio State University (Weiss, 2004) suggests that routine feed sampling is essential. Because it may be difficult and time consuming to sample and formulate rations based on lab results of individual loads, numerous load samples should be collected and analyzed over time. This will allow for estimation of the mean values and also the variation of these estimates. Consequently, it becomes possible to protect against underfeeding a nutrient such as protein by feeding an anticipated mean value of the feed.

FEEDING LEVELS AND PRODUCTION RESPONSES

It is impossible to recommend an optimal inclusion level of CDG, as it depends upon many factors including price and the nutrient content of all available feedstuffs. A number of investigators have evaluated the effects of increasing levels of distillers grains in replacing both forages and concentrates (Powers et al., 1995; Owen and Larson, 1991; Garcia et al., 2004; Kalscheur et al., 2004; Leonardi et al., 2005). Conservative estimates from these studies suggest that 15-20% of the ration DM may be included in a properly formulated ration for a lactating cow. Research also suggests that the addition of CDG to dairy diets usually results in an increase in DMI (Nichols et al., 1998; Powers et al., 1995; Owens and Larson, 1991); however this is not observed in all cases (Leonardi et al., 2005 and Schingoethe et al., 1999). Nevertheless, the increase in DMI is not surprising given that intake is influenced by feed particle size and digestive passage rate (Beauchemin et al., 2005) both of which have been demonstrated to increase in diets containing milling co-products (Boddugari et al. 2001).

In published studies evaluating CDG as a protein supplement, milk production was observed to either be unaffected (Clark and Armmentano, 1993; Owen and Larson, 1991) or increased (Powers et al., 1995; Nichols et al., 1998). Because CDG may contain as much as 13% ether extract (an estimate of crude fat), the high level of fat is one factor believed that may affect milk fat synthesis and as a result limit the inclusion of CDG into dairy diets. This effect was not observed by Leonardi et al. (2005) who evaluated the effects of increasing levels (up to 15%) of CDG and the addition of corn oil to the control diet. These investigators observed an increase in milk and protein yield, thus demonstrating that CDG is a good energy source for dairy cows when the overall diet contained approximately 28% NDF and 5% fatty acids.

Practically, when CDG is introduced into the ration, the inclusion should proceed at a logical and measured pace. Producers should first discuss potential availability of these feedstuffs with their nutritionists. As mentioned, generally speaking the closer the farm is to a plant, the lower the cost will be. Proper evaluation of any ration change should allow the cows to consume the diets for at least three weeks so that cows and their rumen microbes can adapt to the change. Milling products are very palatable and after adaptation, dairy cattle may even increase dry matter intake. If intakes appear to increase, be sure that enough feed is mixed up each day to allow for approximately 5-10% refusal. Final evaluation of the change should include observations of intake, milk production and composition and ultimately consideration of income over feed costs.

SUMMARY AND CONCLUSIONS

Feed co-products from the dry-milling industry are quickly becoming common and cost effective ingredients in dairy diets. Current research suggests that it is possible to include CDG at 20% of the diet DM. When including CDG into dairy diets, nutritionists should ensure that the diet contains adequate levels of lysine, NDF, and effective fiber and they should be mindful of the high concentration of fat in this feedstuff. Future research should be directed towards understanding how diets may be formulated to contain greater than 20% of the diet DM without affecting milk production and composition.

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DDGS IN POULTRY DIETS

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Dried distillers grains feed products are not new to the poultry industry. Such co-products of the brewers industry have been available for quite some time. Distillers dried grains and distillers solubles have been regarded as good sources of vitamins and protein for poultry diets despite known deficiencies of particular amino acids and sometimes an abundance of fiber. Most of the distillers grains and solubles used in the past few decades were derived from barley distillation. On a protein basis, distillers feeds are deficient in the same amino acids as their parent grains. However, the concentration of essential minerals and vitamins increases in the distillers products compared to their parent grains. The official 1984 NRC definition of Distillers Dried Grains with Solubles was "the product after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or grain mixture by condensing and drying at least three-quarters of the solids of the resultant whole stillage by methods employed in the grain distilling industry". The predominating grain shall be declared as the first word in the name. (Taken from "Poultry Feeds and Nutrition", Patrick and Schaible, 1980).

Research conducted in the mid 1980's evaluated the nutritional value of mostly barley distillers grains in poultry diets (Newman et al., 1985; Parsons, 1985; and Benabdeljelil and Jensen, 1989). Newman reported in 1985 that broiler chicks could be fed up to 10% barley distillers grains with equal performance to a corn soy diet. Further fermentation of the distillers grains with a microorganism did tend to improve feed quality of the distillers grains product tested. Benabdeljelil and Jensen, 1989, reported that up to 30% DDGS could be fed to laying hens with no negative effects on egg numbers but with a negative effect on egg size in young hens. They also observed some improvement in shell breaking strength when DDGS was added at a rate of 30%. There was reference to a theory that feeding DDGS may improve interior egg quality (Haugh units) in the laying hen but this theory was not substantiated in this study.

More recently, a renewed interest in the use of corn distillers dried grains has been taken by the poultry industry here in the Midwest due to the sharp increase in corn ethanol producing plants. Interest in using DDGS and DDG in poultry rations, particularly laying hen rations has escalated and usage levels have increased exponentially during the past 5 years. In coincidence with the explosion of ethanol producing plants in the Midwest, (particularly Iowa, Nebraska and Minnesota), Iowa has become the number one egg producing state in the nation with over 20 million layers. Nebraska ranks 8th in the nation with 12 million layers. Poultry feeds have become a target industry for the co-products of the ethanol industry, particularly dried distillers grains with solubles (DDGS). As the interest and use of DDGS has increased, the number of research publications on the "new" feeding value of corn DDGS has also risen. While we have good background information from the feeding of barley DDGS, more current research with corn DDGS has been needed by the poultry industry.

The University of Minnesota has led the field on DDGS research in poultry. A landmark publication by Spiehs, et al., in 2002 from the University of Minnesota, surveyed the nutrient content of DDGS from 10 new ethanol plants in Minnesota and South Dakota. Results of this survey are presented in Table 1. Within the nutrient mean averages, coefficients of variation were less than 5 % for dry matter, calculated M.E. and less than 10% for crude protein, fat, fiber and some amino acids. Unfortunately, coefficients of variation for the first two limiting amino acids in poultry diets, methionine and lysine, were high (13.6 and 17.3, respectively). Coefficients of variation for phosphorus and zinc were also high (11.7 and 80.4%, respectively). Noll et al. (2003) surveyed four commercial plants during the spring of 2002 taking a total of 22 DDGS samples. Nutrient averages reported by Noll are also given in Table 1. Noll reported lower levels of protein, ash, fiber, methionine, lysine and phosphorus compared to the earlier survey by Spiehs, 2002. Noll reported less variation within a plant than between plants. The nutrient showing the most variability was sodium.

A number of recent studies have been conducted in poultry testing the feeding value of DDGS and bioavailability of nutrients in DDGS to poultry. There is quite a bit of interest in the availabililty of phosphorus in DDGS given environmental concerns about phosphorus utilization and accumulation in poultry waste. Amezcua, et al., 2005 reported the bioavailability coefficient for P to be 69%. This is quite high compared to 30% in corn. In a second trial, the researchers investigated three DDGS samples and reported relative phosphorus bioavailabilities ranging from 75 to 102%. This variability was attributed to heat processing in the plant. Lumpkins and Batal (2005) conducted five experiments testing the availability of lysine and phosphorus in DDGS in roosters. They determined the digestibility of lysine to vary between 75 to 100% and phosphorus to be between 54 and 68%. Again, quite a bit of variability in nutrient availability was apparent as different trials were conducted.

Noll and Brannon (2005) conducted a study in turkeys testing the acceptable inclusion level of DDGS in turkey rations as influenced by dietary protein level. They reported that up to 20% DDGS could be fed in turkey tom grower/finisher diets but that when high levels of protein were fed to turkey toms, improved performance could be managed with a 15% inclusion rate.

Table 1. Nutrient value of corn DDGS taken from Spiehs et al., 2002 survey of 10 Minnesota and South Dakota plants

	D.M.	Crude Protein	Fat	Fiber	Ash	M.E.	Arg.	His	Ile	Leu	Lys	Met	Cyst	Phe	Thr	Trp	Val	Phos
	(%)	(5)	(%)	(%)	(%)	(kcal/kg)	- - -	- - -	- - -	- - -	- - -	(%)	- - -	- - -	- - -	- - -	- - -	(%)
MN-SD samples	88.9	30.2	10.9	8.8	5.8	3749	1.20	0.76	1.12	3.55	0.85	0.55	---	1.47	1.13	0.25	1.50	0.89
Old plant values	88.3	28.1	8.2	7.1	6.3	3661	0.92	0.61	1.00	2.97	0.53	0.50	---	1.27	0.98	0.19	1.39	0.90
NRC, 1998 values	93.0	29.8	9.0	---	---	3088	1.22	0.74	1.11	2.76	0.67	0.54	---	1.44	1.01	0.27	1.40	0.83
Feedstuffs reference issue, 1999	93.0	29.0	8.6	9.0	4.8	3848	1.08	0.85	1.08	2.90	0.65	0.65	---	1.29	1.02	0.22	1.43	1.02
Noll, 2003	88.3	27.5	10.0	5.7	3.97	----	1.08	---	0.96	---	0.74	0.49	0.52	---	0.98	0.22	1.32	0.73

Most poultry rations are formulated on a least cost basis with ingredient maximums set by a nutritionist. Current practice by poultry nutritionists is to set a maximum limit of inclusion rate for DDGS in layer rations at 8-10%. More research is needed to justify going higher than these levels at this time.

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CORN DISTILLERS DRIED GRAINS WITH SOLUBLES FOR SWINE

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INTRODUCTION

Previous sections have highlighted the dramatic increase in corn usage for ethanol production. This augmented production of corn for ethanol production has resulted in the production of a variety of co-products, e.g., corn distillers dried grains with solubles (DDGS). Conventionally, the majority of these co-products have been incorporated in ruminant diets (see the Beef Cattle and Dairy Cattle reviews); however, interest has been generated regarding the potential of using products from dry-corn milling for use in swine diets (Knott and Shurson, 2004; Shurson et al., 2004).

Although the focus of this review will be linked to nutrient composition and pig performance related to dry-milling co-products (i.e., DDGS), extrapolations to wet-milling co-products may be plausible inasmuch as newer wet milling applications can be adapted towards using starch for both the production of sweeteners and ethanol.

Table 1. Amino acid concentrations (100% dry-matter basis) of DDGS samples acquired from 10 Midwest ethanol plants (data adapted from Spiehs et al., 2002; University of Minnesota, 2005)

Amino Acid, %	Mean (range)	Standard Deviation	Ratio[1]	Ratio[2]
Lysine	.88 (.61 to 1.06)	.13	1.0	1.0
Methionine	.63 (.54 to .73)	.06	.68	.65
Threonine	1.14 (1.02 to 1.28)	.09	1.24	1.12
Tryptophan	.24 (.18 to .34)	.05	.26	.23

[1] Ratio of amino acids relative to lysine in DDGS.
[2] Ratio of amino acids relative to lysine in corn (Adapted from NRC, 1998)

DISTILLERS DRIED GRAINS WITH SOLUBLES

The dry milling process is reviewed in the Beef Cattle section (see pages 4 and 5). Although the vast majority of co-products generated during ethanol production are marketed and fed as high-moisture feeds, the focus herein will be on dried co-products (DDGS). A designation is made between "newer generation" DDGS (produced from plants built since 1990) and DDGS produced from plants built prior to 1990. Distillers dried grains with solubles produced from older and newer plants differ significantly in nutrient composition and availability. A number of these differences will be highlighted in subsequent sections of this review. Readers are encouraged to consult (University of Minnesota, 2005; Shurson et al., 2004; Spiehs et al., 2002) for critical work and reviews describing nutrient composition and pig performance associated with DDGS.

DDGS NUTRIENT COMPOSITION, VARIABILITY, AND AVAILABILITY

Ethanol production has expanded greatly during the past 10 years. Currently, there are more than 60 ethanol plants in Nebraska, South Dakota, Iowa, and Minnesota. Other sections in this publication have highlighted the variability in nutrient content of DDGS produced at Midwest plants; however, it is important to review the variability of DDGS relative to the impact on diet formulation and nutrient utilization in swine. Table 1 shows the variability in amino acid content from DDGS samples acquired from 10 dry-milling plants located in Nebraska, South Dakota, and Iowa.

The protein quality relative to the ratios of essential amino acids (lysine, methionine, threonine, and tryptophan) in DDGS is similar to corn (relative to lysine; Table 1). Thus, the quality of protein in DDGS is not superior to that in corn; albeit, the concentration of protein and amino acids is increased. This presents a dilemma to the nutritionist/producer inasmuch as in order to maintain appropriate amino acid concentrations and ratios using DDGS, total protein concentration will be increased (unless an upper limit on DDGS inclusion is set).

The variation in DDGS nutrient composition must also be considered within the context of nutrient availability. The majority of studies examining nutrient availability in DDGS have focused on amino acids and phosphorus. Table 2 shows amino acid standard ileal digestibilities adapted from Stein et al., 2005.

Table 2. Standardized ileal digestibility (%) of amino acids from 14 DDGS samples (adapted from Stein et al., 2005) and values referenced from NRC (1998)

Item, %	Range	Mean	NRC (1998)
Lysine	44 to 78	60	59
Methionine	74 to 89	81	75
Threonine	62 to 87	70	65
Isoleucine	67 to 85	73	79
Valine	66 to 84	72	67

Large variation exists for ileal digestibilites of amino acids from DDGS. This finding is consistent with the findings of Fastinger and Mahan (2005) that indicated that lysine true ileal digestibilites of DDGS acquired from five different plants ranged from 67 to 75%. Actual agronomic and production parameters related to the variability in amino acid digestibility remain unquantified. Potential factors related to the variability in DDGS amino acid digestibility may include: genetic variation among corn samples, quantity of solubles added back to distillers grains, and drying temperature and duration prior to distribution. Excessive heat can reduce amino acid availability and has been associated with "older generation" ethanol plants.

It is clear that amino acid deficiencies could arise if DDGS composition is not adjusted for the variation in digestibility. In addition, depending on crystalline amino acid, soybean meal, corn, and DDGS costs, diets formulated may promote nutrient excretion and increase diet cost. Therefore, it is important to not only consider the maximum amount of DDGS in the diet, but also compositional variation related to lysine (nutrient) values.

The energy concentration of DDGS is assumed to be ≥ corn. Metabolizable and digestible energy values for DDGS are estimated from digestibility/metabolizability studies and(or) chemical composition. Digestible and metabolizable energy values for corn and DDGS are presented in Table 3. Metabolizable energy values for DDGS are ≤ compared to corn. In addition, significant variation exists for DDGS energy values between and within studies.

Table 3. Digestible and Metabolizable energy values (kcal/kg; DM basis) of corn and DDGS

Source	DE	ME
Corn (NRC, 1998)	3,961	3,843
DDGS	4,011	3,827
(Shurson et al., 2004)	(3,965)[1]	(3,592)[1]
DDGS (Stein et al., 2005)	3,639	3,378

[1] Calculated from nutrient composition.

Stein et al. (2005) reported an average ME for DDGS of 3,378 kcal/kg; however, the range of values determined from metabolism trials was 3,058 to 3,738 kcal/kg. These reported energy values are significantly greater than values previously reported for older generation DDGS (see NRC, 1988). The increased NDF in DDGS is offset by the increased oil concentration and does not appear to limit inclusion in the diet on DE or ME basis; however, studies that show a reduction in growth performance, with little to no change in feed intake, suggest that energy values may be overestimated for DDGS. Results from work conducted by Hastad et al. (2004) indicate that DE and ME values estimated from metabolism trials (3,800 and 3, 642 kcal/kg, respectively) were 6 to 15% greater than estimates determined directly from growth performance data. The discrepancy between values estimated from metabolism and growth studies was attributed to differences in feed intake. Individually-fed pigs used in metabolism studies typically consume more feed than pigs reared in research group-housing situations or production units.

The phosphorus concentration in DDGS is considerably greater than corn (.89 versus .28%; Shurson et al., 2004). In addition, the relative bioavailability of P in DDGS appears to be high (90%). Accordingly, available P in DDGS can be calculated as high as .80%. Stein et al. (2005) estimated that total tract digestibility of P from DDGS was only 55%. The phosphorus bioavailability estimates for DDGS are made relative to a standard source, e.g., dicalcium phosphate. It is assumed that the availability of P from dicalcium phosphate is 100%. Studies have shown that the total tract digestibility of P from dicalcium phosphate is approximately 70% (Jongbloed and Kemme, 1990). Therefore, correcting P % in DDGS using relative bioavailability may overestimate P available to the pig and increase P excretion.

DDGS AND GROWTH/ REPRODUCTIVE PERFORMANCE

Corn distillers dried grains with solubles can be used effectively in nursery, growing-finishing, gestation, and lactation diets. The majority of nursery, growing-finishing, and lactation studies have used DDGS inclusion percentages < 30%; however, gestation studies (diets) have included up to 50% DDGS. Subsequent reference to maximum DDGS inclusion percentages are provided in the context of performance criteria and not evaluated using economic models. A number of studies cited in this review were presented as proceedings and(or) meeting abstracts. The reader is encouraged to review the literature cited section.

NURSERY PIGS

Whitney and coworkers (2004) conducted two nursery experiments using diets formulated with 0 to 25% DDGS. Experiments were similar in design; however, the second experiment used pigs that weighed less (7.10 and 5.26 kg, respectively) than the previous study. The inclusion of up to 25% DDGS had no effect on ADFI, ADG, and ADG/ADFI throughout a three-phase nursery regimen (first experiment). In the second experiment, lighter pigs had reduced ($P < .05$) ADFI during phase 2, and for overall nursery period ($P < .09$). The cause for the reduced feed intake in the second experiment could not be determined. Palatability of diets containing > 25% DDGS may have been a factor. Therefore, DDGS incorporation in nursery diets for pigs weighing less than 7 kg is cautioned. Diets used in the aforementioned study were formulated to be isolysinic (1.34%); however, analyzed dietary CP was increased 25% from the 0 to 25% DDGS diets. Therefore, it is assumed that N excretion would be significantly increased for pigs consuming the 25% DDGS diet.

GROWING-FINISHING PIGS

Results documenting the effects of DDGS inclusion on growing-finishing pig performance vary. Again, studies conducted with older generation DDGS will not be cited in this review. University of Minnesota researchers (Whitney et al., 2001) conducted a study to investigate the effects of including 0, 10, 20, and 30% DDGS on growth performance (28 to 115 kg; 5-phase growing-finishing sequence). Average daily gain and ADG/ADFI tended to be reduced for pigs consuming diets with greater than 10% DDGS. There was a linear decrease ($P < .03$) in dressing percentage with increasing dietary DDGS concentration. Hastad and coworkers (2005) conducted several experiments with growing (19 to 27 kg) pigs to determine the effects of DDGS on feed intake and diet palatability. The inclusion of 30% DDGS reduced ($P < .05$) ADFI compared to the corn-soybean control. Results from the palatability study showed that pigs preferred corn-soybean meal diets to diets containing DDGS.

Cook et al. (2004) conducted a farrow-to-finish study that used diets containing 0 to 30% DDGS. No overall effects of DDGS on ADG, ADFI and feed efficiency were observed. Mortality rate decreased linearly ($P < .05$) from 6.0% (0% DDGS) to 1.6% (30% DDGS). However, a linear decrease (77.3 to 75.6% $P < .05$) in carcass yield was reported. Clearly, these observations heighten the importance that factors of economic importance must be considered in addition to standard growth and carcass measurements when assessing the value of DDGS. Not all studies have shown reduced performance using as much as 30% dietary DDGS. DeDecker et al. (2005) showed that ADG, feed efficiency, and carcass composition were not different among DDGS treatments (0, 10, 20, 30% DDGS).

Because DDGS contains 10 to 12% lipid, caution should be taken when formulating finishing diets. Excessive intake of lipid (corn oil) can contribute to "soft" fat (high iodine no.). Therefore, it has been recommended that DDGS inclusion be limited to < 20% (Shurson et al., 2004).

GESTATION AND LACTATION

Typically, maximum DDGS inclusion percentages for gestation diets are greater than for other classes of swine (up to 50%). Studies investigating the incorporation for DDGS in lactation diets have not usually exceeded 20%. Also, maximum inclusion percentages for DDGS in gestation and lactation diets have often been limited by the experimental design (i.e., recommendations were made at the highest DDGS inclusion percentage used in the experiment). Relatively few studies investigating the role of DDGS in gestation/lactation diets have been published during the past 10 years.

Monegue and Cromwell (1995) examined the effects of feeding 0, 40 or 80% DDGS during gestation. Subsequently, all sows were fed corn-soybean meal diets (with ad libitum access) during a 28-d lactation. No differences ($P > .20$) among treatments were observed for farrowing rate or litter performance; however, litter size (born and weaned) was numerically reduced for sows fed diets containing 80% DDGS during gestation.

Wilson and coworkers (2003) studied the interaction between DDGS feeding during gestation and lactation (two parities). Dietary treatments were setup as; 0 or 50% DDGS during gestation, and(or) 0 or 20% DDGS during lactation. Pooled among treatment combinations, no differences ($P > .10$) were observed for gestation weight gain, litter, or lactation performance between sows fed 0 and 50% DDGS during gestation. Interestingly, sows fed 0% DDGS during gestation and lactation, weaned fewer pigs during parity 2. Other dietary effects appeared transitory and were not observed during the second gestation/lactation cycle. It appears that DDGS consumption during gestation might benefit DDGS utilization during lactation. Sows that received gestation diets that contained 0% DDGS during gestation and 20% DDGS during lactation had reduced ($P < .01$) ADFI for the first 7 d postpartum. Again, the effects were only observed during the first gestation/lactation cycle.

Hill et al. (2005) conducted an experiment that explored the effects of beet pulp and DDGS inclusion in sow lactation diets. Dietary treatments were comprised of: 1) 5% beet pulp, or 2) 15% DDGS. Sows had ad libitum access to diets (1.2% lysine, .90% Ca, and .84% P) that were provided during an 18-d lactation period. Dietary treatment did not effect lactation performance. Fecal grab samples taken on d 7, 14, and 18 of lactation indicated that P excretion was reduced (d 14; $P < .02$) for DDGS vs beet pulp diets.

DDGS AND PIG HEALTH

Very little research has been conducted to define the relationship between dietary DDGS and swine health. Nonstarch-polysaccharides and oligosaccharides have been demonstrated to have beneficial effects on swine health (see Grieshop et al., 2001). Because DDGS contains as much as 45% NDF (DM basis), it has been investigated as a potential mediator of pig health. Spiehs et al. (2005) conducted a growing-finishing study to determine if a Salmonella challenge could be ameliorated by feeding diets containing 50% DDGS. Treatments were: 1) 5-phase control diet sequence, 2) control + polyclonal antibody, and 3) control + 50% DDGS. Unfortunately, inoculation with salmonella typhimuerium did not elicit an immunological response (create an infection) and no treatment effects were detected.

Two studies were conducted by Whitney et al. (2003) to examine the interaction between DDGS and lawsonia intracellaris (causative bacteria of proliferative ileitis) in nursery pigs. These two studies differed in terms of the severity of the lawsonia intracellaris dosage. Challenged pigs received 1.5×10^9 lawsonia intracellaris in Exp. 1 and 50% of the dosage in Exp. 2. The ileitis challenge successfully increased the number of proliferative lesions in both experiments; however, DDGS (10% of the diet, as-fed basis) was only effective at reducing lesions (similar to antimicrobial treatment) in Exp. 2. Therefore, it appears that scenarios where a low- to moderate-ileitis challenge is presented, DDGS (> 10%) may facilitate a reduction in proliferative ileitis.

SUMMARY

The nutrient composition and availability in DDGS is variable. Irrespective of this inherent variability, DDGS is a good dietary source of energy, amino acids, and phosphorus for growing-finishing and reproducing swine. Readers are encouraged to evaluate the effects of DDGS on production criteria presented in this review in conjuction with economic factors associated with diet formulation and production systems.

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DEFINITIONS

Dry-milled: the process by which the entire corn kernel is ground into a meal and then fermented into alcohol.

Wet-milled: steeped in water with or without sulfur dioxide to soften the kernel in order to facilitate the separation of the various component parts.

Corn Distillers Dried Solubles: obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain mixture by condensing the thin stillage fraction and drying it by methods employed in the grain distilling industry.

Corn Distillers Dried Grains: obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or grain mixture by separating the resultant coarse grain faction of the whole stillage and drying it by methods employed in the grain distilling industry.

Corn Distillers Dried Grains with Solubles (DDGS): product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at _ of the solids of the resultant whole stillage by methods employed in the grain distilling industry.

Distillers Wet Grains (WDG): product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain mixture. The guaranteed analysis shall include the maximum moisture.

Corn Gluten Feed (DCGF = dried; WCGF = wet): part of the commercial shelled corn that remains after the extraction of the larger portion of the starch, gluten, and germ by the processes employed in the wet milling manufacture of corn starch or syrup. It may or may not contain one or more of the following: fermented corn extractives, corn germ meal.

Corn Gluten Meal: dried residue from corn after the removal of the larger part of the starch and germ, and the separation of the bran by the process employed in the wet milling manufacture of corn starch or syrup, or by enzymatic treatment of the endosperm. It may contain fermented corn extractives and/or corn germ meal.

Steep-extracting: soaked in water or other liquid (as in the wet milling of corn) to remove soluble materials.

Steepwater: water containing soluble materials extracted by steep-extraction

Germ: the embryo found in seeds and frequently separated from the bran and starch endosperm during milling.

Stillage: the mash from fermentation of grains after removal of alcohol by distillation.

Distillation Solubles: stillage filtrate

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Credit Card Number:____________________________ Expiration Date:______________

Send Invoice to:
Sharon Senesac, AAFCO Assistant Secretary-Treasurer
P.O. Box 478
Oxford, IN 47971, USA
Telephone: (765) 385-1029, Fax: (765) 385-1032
E-mail: sharon@aafco.org

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