USE OF DISTILLERS GRAINS AND CO-PRODUCTS IN RUMINANT DIETS

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The fermentation of grains to produce alcohol yields whole spent stillage from which wet distillers grains (WDG) and thin stillage are obtained by screening and pressing or centrifugation. Usually, WDG are dried to yield dried distillers grains (DDG), or dried distillers grains with solubles (DDGS) if solubles in the thin stillage are added back to the grains at drying. The solubles in the thin stillage may also be partially or totally dried to make condensed distillers solubles (CDS) or dried distillers solubles (DDS), respectively. Of these co-products, DDG and DDGS are the most commonly used, probably because of ease of handling, storage, and shipping. However, the high cost of drying has led people to investigate the possibility of feeding wet distillers byproducts to ruminants.

NUTRIENT COMPOSITION

Table 1 shows the chemical composition of distillers grains co-products from various grains. These products are generally characterized by higher protein, fat, NDF and ash, and lower starch contents compared with the source grain. Distillers dried grains and DDGS contain moderate levels of protein, and high levels of fat and fiber, which makes them attractive for use in ruminant diets. However, like many other byproduct feeds, the nutrient content in distillers byproducts can be highly variable.

A recent survey conducted at the University of Minnesota (Harty et al., 1998) showed substantial variation in DDGS composition both within and across ethanol production facilities (Table 2). The survey involved a total of 95 samples from eight different production facilities located in Minnesota (5), South Dakota (2), and Nebraska (1). One sample was collected from each production facility on the first and third Tuesday of each month, over a 6-month period. The survey showed large variations for all nutrient values across production facilities ($P < 0.01$) (Table 2). Chase (1991) reported similar variations for CP, NDF and ether extract. Within production facility, DM, ether extract, ash, soluble protein, rumen degradable protein (RDP), rumen undegradable protein (RUP), and intestinal availability of protein (IACP) showed the largest variations, whereas CP, NDF, and ADF contents showed considerably less variation than other nutrients. Factors influencing the composition of distillers byproducts include the type of grain used, drying method, amount of solubles added, and fractionation of particle size.

Although corn is the major grain used in alcohol production, wheat, barley, rye, and sorghum (milo) may also be used. Lee et al. (1991) studied the composition of DDG and DDGS from corn, wheat, and mixtures of the two grains and found that DDG or DDGS from corn contained lower protein, lower fiber, but higher fat contents than the same co-products from wheat (Table 1). As corn decreased and wheat increased in the mixture, protein and fiber increased, whereas fat content decreased. Similarly, Canadian Prairie spring wheat contained more protein and more fiber, but less fat than durum wheat (Table 1). Similar observations were made by Dong et al. (1987) on corn, white wheat, and red wheat DDGS (Table 1). When grain mixtures are used for alcohol production, the name of the grain contributing the larger proportion in the mixture is usually given to the byproduct; i.e. corn DDG or DDGS may contain grains other than corn.

Drying method is a primary factor in determining the overall quality of distillers grains (Rasco et al., 1989). In their experiment, Rasco et al. (1989) found that protein and NDF contents were the most affected by drying method. The effect of drying method on protein content was attributed to the loss of fine particles during drying. The heat applied during drying renders some of the protein in distillers grains insoluble in the neutral detergent solution, giving the appearance of higher NDF content in the dried product.

Compared with distillers grains, the protein content in distillers solubles is lower whereas the ash content is much higher (Lee et al., 1991; Belyea, 1994). Belyea (1994) also indicated that the composition of distillers solubles show large variations. Therefore, the protein content of DDGS will vary depending upon the amount of solubles added. This will also affect protein solubility and degradability in the rumen.

A subtle yet significant source of variation in the composition of distillers grains is the fractionation of particle size that may be caused by handling. Wu and Stringfellow (1986) conducted a particle size fractionation experiment on corn DDG and DDGS and showed protein and NDF are the components that are mostly affected. They used sieves with openings ranging from 177 to 841 um (80 to 25 mesh screens). The DDG and DDGS tested were obtained from a commercial distillery and contained 26% CP and 58% NDF for DDG, and 29.5% CP and 40.5% NDF for DDGS. With DDG, the fraction going through the 500 um (35 mesh) screen represented 36% of the total sample and contained 38% CP and 43% NDF, whereas the fractions retained on bigger screens contained from 16 to 25% CP and from 58 to 71% NDF. Fractionation was done on a 100-lb sample. In the case of DDGS, using a 1-lb sample, WU and Stringfellow (1986) found that the fraction going through the 500 um represented 65% of the sample and contained 35% CP and about 30% NDF. The fractions retained on bigger screens contained 17 to 20% CP and 58 to 62% NDF. Additionally, reports indicate ash is a primary component of stillage solubles, whereas most of the lipid in distillers grains products is associated with the insoluble solids (Rasco et al., 1989; Lee et al., 1991). These findings suggest that handling that causes particle separation will result in considerable variation of DDG or DDGS composition. Harty et al. (1998) found that fine particles (< 1 mm) represented 58% of the sample weight on average across 8 ethanol production facilities; values ranged from as little as 19% to as much as 94%.

Table 1. Chemical composition of co-products of alcohol production from various grains.

Source grain	Co-product	DM	Starch	Crude protein	Ether extract	NDF	Ash
			- - - - - - - - - - - - % of DM - - - - - - - - - - - -				
Corn[1]	DDG	. . .	1.3	32.9	17.6	. . .	2.5
Corn[1]	DDGS	. . .	1.6	28.7	17.6	. . .	5.2
70% corn: 30% wheat[1]	DDG	. . .	1.3	38.0	12.4		3.2
70% corn: 30% wheat[1]	DDGS	. . .	1.1	33.5	12.1		5.3
30% corn: 70% wheat[1]	DDG	. . .	2.1	40.2	9.0		3.8
30% corn: 70% wheat[1]	DDGS	. . .	1.8	35.9	9.9		4.9
Canadian Prairie Spring wheat[1]	DDG	. . .	1.4	45.2	4.7		3.7
Canadian Prairie Spring wheat[1]	DDGS	. . .	1.5	41.9	3.9		5.9
Durum wheat[1]	DDG	. . .	0.5	48.7	6.2		3.2
Durum wheat[1]	DDGS	. . .	0.5	42.7	5.6		5.3
White wheat[2]	DDGS	92.0	. . .	40.4	3.2	29.2	5.4
Red wheat[2]	DDGS	94.3	. . .	34.4	3.4	25.9	5.1
Corn[2]	DDGS	90.3	. . .	31.6	8.9	25.0	4.1
Corn[3]	DS	42.1	. . .	18.7	13.9	. . .	10.6
Barley[4]	WDG	35.5	. . .	26.9	. . .	38.0	. . .
Barley[4]	DDG	87.5	. . .	28.7	. . .	56.3	. . .
Sorghum[5]	WDG	23.5	10.2	31.6	11.3	45.4	2.5
Sorghum[5]	DDGS	91.4	7.4	31.4	11.8	51.1	1.8
Corn[6]	WDG	27.9	6.2	28.1	15.4	44.3	3.1
Corn[6]	TS	4.4	25.1	19.0	9.2	13.3	6.7
Sorghum (bronze)[7]	DDGS	90.4	. . .	26.6	8.1	. . .	4.9
Sorghum (yellow)[7]	DDGS	88.9	. . .	25.6	8.0	. . .	4.2

Source: [1] Lee et al., 1991; [2] Dong et al., 1987; [3] Belyea, 1994; [4] Weiss et al., 1989; [5] Lodge et al., 1997; [6] Ham et al., 1994; [7] Hancock, 1995;

Table 2. Nutrient composition of distillers dried grains with solubles from different ethanol production facilities[1].

	Processing Facility								Across plant variation			Within plant variation
Item[2]	A	B	C	D	E	F	G	H	Mean	CV	P	CV range
Dry matter, %	91.2	93.4	92.4	94.4	91.9	93.3	92.6	92.5	92.7	1.1	< 0.01	0.6 – 3.7
NDF, % of DM	44.1	48.2	47.2	49.6	55.1	50.6	47.3	47.9	48.8	6.6	< 0.01	4.0 –10.3
ADF, % of DM	14.4	16.3	16.3	14.8	16.6	16.9	14.3	14.1	15.5	8.1	0.04	12.9 – 28.1
EE, % of DM	11.8	10.0	11.2	8.8	9.4	12.4	10.1	10.6	10.5	11.6	< 0.01	12.9 – 38.5
Ash, % of DM	4.6	4.4	3.9	5.2	3.2	4.4	4.8	4.0	4.3	14.3	< 0.01	8.2 – 19.7
CP, % of DM	29.4	27.7	28.8	29.9	30.9	31.3	30.3	32.3	30.1	5.0	< 0.01	2.0 – 5.8
SP, % of CP	11.6	8.7	9.4	9.6	6.0	12.6	10.7	9.4	9.8	19.5	< 0.01	11.4 – 61.2
ADIP, % of CP	4.9	10.5	10.7	8.1	7.3	11.6	5.8	5.4	8.0	33.8	< 0.01	34.5 – 61.3
RDP, % of CP	52.0	42.5	47.5	52.2	37.3	51.3	45.8	44.1	46.6	11.2	< 0.01	6.7 – 15.1
RUP, % of CP	47.9	57.5	52.5	47.8	62.6	48.7	54.2	55.8	53.4	9.8	< 0.01	6.1 – 11.9
IAP, % of RUP	81.9	73.8	73.8	77.8	77.8	75.9	79.3	78.7	77.3	3.5	< 0.01	4.1 – 7.0
IAP, % of CP	39.1	42.5	38.8	37.1	48.7	36.6	42.9	43.9	41.3	9.9	< 0.01	5.1 – 15.7
PS1, % of sample	17.4	1.8	6.2	10.0	14.6	16.9	10.6	5.2	10.3	54.6	< 0.01	40.8 –144.2
PS2, % of sample	50.7	12.5	22.0	18.1	36.9	33.4	41.6	36.2	31.4	30.0	< 0.01	21.1 – 55.3
Fines, % of sample	31.9	85.7	71.8	71.9	48.5	49.7	47.8	58.5	58.2	20.6	< 0.01	12.5 – 60.1

[1] Means are least squares means.

[2] DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, EE = ether extract, CP = crude protein, SP = soluble protein (in borate phosphate buffer), ADIP = acid detergent insoluble CP (ADIN x 6.25), RDP = rumen degradable protein, RUP = rumen undegradable protein, IAP = intestinally available protein, PS1 = fraction having a particle size greater than 2 mm, PS2 = fraction having a particle size less than 2 mm but greater than 1 mm, fines = fraction having a particle size less than 1 mm.

PROTEIN QUALITY OF DISTILLERS GRAINS

Distillers grains are a good source of protein and other nutrients in ruminant diets. Distillers dried grains and DDGS contain a significant amounts of both rumen degradable (RDP) and rumen undegradable protein (RUP), and post-ruminal digestibility of the RUP is generally high (Ingalls, 1994; Stern et al., 1995; O'Mara et al., 1997).

Typical RUP values for corn DDG and DDGS are 54 and 47% of the CP (NRC, 1989), although large variations can be found in the literature (Nakamura et al., 1994; Grings et al., 1992; Powers et al., 1995). Nakamura et al. (1994) reported RUP values ranging from 16 to 80% for DDG. In a recent survey, researchers (Harty et al., 1998) at the University of Minnesota found RUP for DDGS averaged 53% of the CP (n = 95) (Table 2), but ranged from 40 to 68%. Similar values have been reported by Stern et al. (1995). Factors affecting RUP content of DDG and DDGS include type of grain used, drying method (temperature and time), amount of solubles added, the laboratory technique used. In a survey conducted at the University of Minnesota, soluble CP was found to account for about 36% of the variation of RUP in 96 samples obtained from 8 different ethanol production facilities over a 6-month period (Table 3).

Good quality RUP must be digestible and available for absorption in the small intestine. In the case of distillers grains, Nakamura et al. (1994) obtained in vivo estimates of true N digestibility averaging 98% for DDG. In addition, Stern et al. (1995) reported in vitro estimates of intestinal digestibility of RUP ranging from 72 to 85% (n = 5; average = 81%) for DDG. More recently, Harty et al. (1998) tested 95 samples of DDGS and obtained in vitro estimates of intestinal digestibility of RUP that averaged 77%, and ranged from 71 to about 94%. Using the mobile bag technique, Ingalls (1994), and O'Mara et al. (1997) showed ileal disappearance of individual amino acids in the RUP (residual protein after rumen incubation) is quite high, ranging from 82 to 97% for barley DDGS, and from 76 to 84% for corn DDG, respectively. However, there is concern that some of the protein, though hydrolyzed by enzymes in the gastro-intestinal tract or in vitro, may not be utilized by the animal (Nakamura et al., 1994b). In addition, protein digestibility or total amino acid digestibility may mask digestibility problems for individual amino acids. Reduced efficiency of protein utilization has been reported when animals were fed distillers grains (Klopfenstein, 1991; Cromwell et al., 1993), presumably because the protein in distillers grains had been heat damaged and, thus, was poorly utilized (Dong et al., 1987; Klopfenstein, 1991; Chaudhry and Webster, 1993; Cromwell et al., 1993; Nakamura et al., 1994b), or because of a lysine deficiency.(Dong et al., 1987; Cromwell et al., 1993; Armentano, 1994).

Corn protein is deficient in lysine, and so are corn products such as distillers grains. Table 3 shows the amino acid profile of various distillers co-products. Dong et al. (1987) reported that the amino acid profile of distillers grains is similar to that of the parent grain. As a result, differences in amino acid composition of distillers grains reflects differences between amino acid composition of the parent grains.

During the process of alcohol production, the grain is cooked to gelatinize starch before enzymatic degradation and yeast fermentation. Additionally, heat is used to dry the wet distillers grains to produce DDG or DDGS. Heating of feeds can reduce protein degradation by ruminal microbes and increase efficiency of protein utilization by ruminants. However, excessive heating can actually render some of the protein totally unavailable to the animal (NRC, 1985; Stern et al., 1994), and decrease efficiency of protein utilization. Therefore, the potential for heat damage of protein in distillers grains exists (Klopfenstein, 1991; Nakamura et al., 1994b). However, the point at which the negative effects of heating outweigh the beneficial effects has not been established (Van Soest, 1989; Merchen, 1994).

Table 3. Amino acid composition of distillers grains from various grains and of corn distillers solubles.

	Distillers byproduct					
Amino acid	Corn DDGS[1]	Bronze sorghum DDGS[2]	Yellow sorghum DDGS[2]	Corn distillers solubles[3]	Barley DDG (% of DM)[4]	Barley WDG (% of DM)[4]
	- - - - - - - - - - - - % as fed - - - - - - - - - - - - -					
Arginine	1.06	0.97	0.91	0.84	1.81	1.81
Histidine	0.72	0.57	0.55	0.58	0.33	0.22
Isoleucine	1.00	0.99	0.95	0.77	0.82	0.72
Leucine	3.33	2.55	2.39	1.31	2.10	1.88
Lysine	0.70	0.60	0.55	1.18	0.39	0.61
Methionine	0.51	0.46	0.42	0.27	0.29	0.25
Phenylalanine	1.45	2.02	1.83	0.68	1.15	1.01
Threonine	1.03	0.87	0.79	0.87	0.99	0.80
Tryptophan	0.19	0.22	0.21	0.18	. . .	. . .
Valine	1.35	1.25	1.24	1.02	1.10	0.93

[1] N = 9 (Cromwell et al., 1993).
[2] N = 1 (Hancock, 1995). Phenylalanine values include tyrosine.
[3] N = 6 (Belyea, 1994).
[4] Weiss et al., 1989.

COLOR AND ADIN AS INDICATORS OF PROTEIN QUALITY OF DISTILLERS GRAINS

There has been much interest in using acid detergent insoluble N and color darkness as indicators of heat damage in distillers grains, presumably because ADIN represents indigestible N, and darkness suggests excessive heating. Van Soest (1989) indicated that the general belief in the indigestibility of ADIN is based on the early work of Yu and Thomas (1976) and Goering et al. (1973) on heat-damaged forages. However, since then, there has been evidence that ADIN in non-forage feeds behaves differently than ADIN in forages, as a large portion of ADIN (up to 58%) in non-forage feeds is digestible (Britton et al., 1986; Weiss et al., 1989, Van Soest, 1989; Van Soest and Mason, 1991). While the relationship between ADIN and N digestibility was found to be strong in forages (Yu and Thomas, 1976), it has not been consistent in non-forage feeds such as distillers grains. Some studies showed a strong negative relationship between ADIN and N digestibility (Van Soest, 1989; Van Soest and Mason, 1991; Waters et al., 1992; Nakamura et al., 1994a), while others found ADIN was a poor indicator of protein unavailability (Britton et al., 1986; Weiss et al., 1989; Nakamura et al., 1994a). One possible explanation for these apparently contradictory findings may be that the relationship between ADIN and protein digestibility is not constant across ADIN values. Evidence of this can be found in the studies by Nakamura et al. (1994a). In one study, ADIN content in protein sources ranged from 11.5 to

59.5% of N, and a strong negative correlation (r^2 = .66) was found between ADIN and apparent N digestibility. However, in another study, ADIN contents in protein supplements ranged from 7.8 to 27.9% of N, and the correlation between ADIN and apparent N digestibility was poor (r^2 = .24).

In a recent study by Harty et al. (1998), 98 samples were evaluated for the relationship between ADIN and intestinal availability of protein determined in vitro. The ADIN ranged from .78 to 35% of N. Over the entire range of the data, the correlation between ADIN and intestinal availability of protein (IACP) or intestinal availability of RUP (IARUP) was poor (r = -.24 and -.42, respectively). The best correlation between ADIN and IARUP (r = -0.87) was obtained when only ADIN values greater than 13% of N (n = 17) were used. And even within this range, ADIN was very poorly correlated with IACP (r = -0.17). Cromwell et al. (1993) found a strong negative correlation between ADIN and nutritional quality of DDGS for pigs. In their study, ADIN ranged from 8.8 to 36.9. Van Soest (1989) indicated that normal feeds contain a N fraction that is unavailable, ranging from 3 to 15%. He suggested ADIN values within this range may not be high enough for negative effects.

The data on the relationship between color and protein quality of distillers grain is very limited. Cromwell et al. (1993) used a special apparatus to measure the variation in color of DDGS. For each sample, three color scores were obtained: L (lightness, changing from black to white), chromaticity a (redness), and chromaticity b (yellowness). For lightness, the smaller the score, the darker the sample appears. For redness and yellowness, the higher the score, the more red or yellow the sample appears. Lightness in this study ranged from 53.3 (lightest) to 28.9 (darkest), and was correlated to ADIN (r = -.79), with ADIN increasing as samples got darker. A similar evaluation was done in the study by Harty et al. (1998). In their study, Harty et al. (1998) observed L scores ranging from 39.8 (darkest) to 59.1 (lightest), but observed poor correlation between lightness and IAPRUP (r = 0.32), or IACP (r = .17). This is in apparent contradiction to the findings by Cromwell et al. (1993). However, when the analysis was restricted to samples with ADIN > 13% of N, then lightness was strongly correlated to both ADIN (r = -0.80) and IARUP (r = -0.80). These findings suggest that if the color of a sample of distillers grains looks very dark, it may be a good idea to have the sample tested for ADIN. However, color by itself is not a good indicator of protein damage in distillers products.

FEEDING DISTILLERS GRAINS BYPRODUCTS TO RUMINANTS

During the past 10 years, much of the research on feeding distillers byproducts to beef cattle was conducted at the University of Nebraska (Larson et al., 1993; Ham et al., 1994; Nakamura et al., 1994, Lodge et al., 1997a; Lodge et al., 1997a).

The work by Larson et al. (1993) and Ham et al. (1994) was summarized by Klopfenstein and Stock (1993) and by Klopfenstein (1996). These studies show corn wet distillers byproducts (WDB; a combination of WDG and thin stillage) or corn DDGS have greater value for energy for growth than dry rolled corn (1.28 to 1.69 times greater), and can also be effectively used as a source of protein in growing and finishing diets. Daily gain and efficiency of feed conversion of finishing calves or yearling steers fed distillers co-products were consistently improved over those of animals fed dry rolled corn (Klopfenstein, 1996). These findings were in agreement with some earlier work (Firkins et al., 1985). In addition to greater energy content of corn distillers grains due to a higher fat, and, in the case of WDB, ethanol contents, maintaining good rumen health was identified as a major factor contributing to improved performance when corn distillers co-products were fed in partial replacement of dry rolled corn. The beneficial effect on rumen health was attributed to the large reduction in starch intake and increased intake of highly digestible fiber when distillers co-products were fed, thus possibly preventing subacute acidosis. In these studies, animals fed WDB also performed better than those fed DDGS. However, handling and storage difficulties associated with the high moisture content (68.6%, on average) of WDB limits its use to large feedlot operations.

More recently, the work of Lodge et al. (1997a) showed sorghum WDG and WDB had energy values similar to those of dry rolled corn, whereas sorghum DDGS had lower energy value than corn. Compared to corn WDG, sorghum WDG had lower apparent organic matter, true N and apparent N digestibility, but similar NDF digestibility.

Ham et al. (1994) found WDB and DDGS were better utilized as sources of protein than urea by growing calves. They also concluded that drying distillers grains to produce DDGS did not adversely affect protein quality, as ADIN content (5.9, 13.9, and 14.8% of total N in test diets) had no effect on daily gains or efficiency of protein utilization. However, subsequent work by Nakamura et al. (1994) showed reduced protein efficiency by 34% when ADIN in DDG increased from 11.3% to 23.8% of total N, although true N digestibility was decreased by only 7%. Klopfenstein (1991) indicated that this type of heat damage due to excessive heating probably does not occur routinely.

Research on feeding distillers grains to dairy cattle has been reviewed by Chase (1991) and, more recently, by Linn and Chase (1996). There is little information available on feeding wet distillers grains to dairy cattle. The reviews indicate dried distillers grains are a good source of RUP. Performance results in response to feeding distillers grains, although variable, show DDG and DDGS can support similar or greater milk yields than soybean meal. However, less than optimum performance can result if an excessive quantity of distillers grains (> 26% in the diet DM) is fed, possibly due to a shortage in RDP, low lysine intake, and/or limited protein availability due to heat damage. Distillers grains can replace some of the forage fiber to maintain milk fat test, but have little ability to stimulate chewing. The review by Linn and Chase (1996) also discusses various ways to estimate the economical value for DDGS. Recent work suggest distillers grains can be effectively used in dairy cattle diets if supplemented with lysine (Armentano, 1994; Nichols et al., 1998).

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