The Nutritive Value of Thin Stillage and Wet Distillers' Grains for Ruminants
- Review -

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ABSTRACT : Thin stillage and distillers' grains are byproducts remaining after alcohol distillation from a fermented cereal grain mash. Both byproducts are used as energy and protein sources for ruminants. Due to its liquid nature, more than 50% of thin stillage bypasses the rumen. Thin stillage can be fed alone or in combination with distillers' grains. However, a better utilization by beef cattle is anticipated when thin stillage replaces water as a fluid source. Ruminal undegraded protein content of distillers' grains is greatly affected by type of cereal grain and by drying. Corn distillers' grains have a higher ruminal undegraded protein content than wheat distillers' grains while dried distillers' grains have a higher ruminal undegraded protein content than the wet distillers' grains. Wet and dried distillers' grains can replace up to 50% of corn grain in beef cattle diets without affecting animal performance. The estimated NEg of corn distillers' grains for beef cattle ranges from 100 to 169% of that of corn. In general, wet corn distillers' grains have a higher NEg value than dried corn distillers' grains and the addition of thin stillage improves the NEg of distillers' grains. Improved performance of ruminats fed distillers' byproducts can be attributed to high digestible fiber content, improved rumen environment and a shift in organic matter digestion from the rumen to the small intestine. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 11 : 1609-1618)*

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INTRODUCTION

Alcohol production from cereal grains involves the conversion of starch to alcohol through enzymatic hydrolysis and yeast fermentation. The fermentation of cereal grains for alcohol production has been detailed by Ingledew (1993). At the end of the fermentation process, alcohol is distilled by steam and the residues (whole stillage) are usually pressed to separate thin stillage from distillers' grains. In some situations, thin stillage is centrifuged to produce a liquid (distillers solubles) and a solid (centrifuged solids) fraction (Wu et al., 1984; Lee et al., 1991). Ham et al. (1994) described a different separation method where fermented corn mash is pressed to separate the solids (distillers' grains) from the liquid. The liquid is then distilled to produce alcohol and thin stillage.

Corn is the most common substrate for ethanol production due to its abundance and its greater yield of ethanol relative to other cereal grains (Aines et al., 1986). In western Canada, however, wheat is the main fermentation substrate due to its availability. Different proportions of other grains such as barley, rye, and triticale are usually used especially during high wheat prices (Mustafa et al., 2000a, b). Other cereal grains such as sorghum have been used in the United States (Lodge et al., 1997).

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Distillers' byproducts have been recognized as excellent protein and energy sources for ruminants. This is mainly due to their high digestible fiber content and ruminal escape protein levels. Extensive research has been conducted to establish the feeding value of distillers' byproducts for ruminants. The objective of this paper is to review the available research data regarding the nutritive value of distillers' byproducts for ruminants with emphasis on thin stillage and wet distillers' grains.

THINS STILLAGE AND DISTILLERS' GRAINS AS FERMENTATION RESIDUES

The fermentation residues account for 29 (corn) to 41% (barley) of the original grain (table 1). The higher percentage of fermentation residues in barley, relative to other grains, is due to the high hull content of barley. Distillers' grains constitute the largest portion of the fermentation residues and the ratio of fermentation residues (distillers' grains:thin stillage) is fairly similar across cereal grains (table 1).

CHEMICAL COMPOSITION OF THIN STILLAGE

The chemical composition of distillers' byproducts is influenced by the type and cultivar of cereal grain used in the fermentation process and the efficiency by which starch is converted to alcohol (table 2). Generally, wheat thin stillage has the highest CP and

Table 1. Fermentation residues from alcohol distillation of cereal grains

	Cereal grain			
	Wheat[1]	Barley[2]	Corn[3]	Sorghum[4]
Fermentation residues (% of grain)	35	41	29	32
Distillers' grains (% of residues)	74-76	72	69-72	71
Thin stillage (% of residues)	21-26	28	29-31	29

[1] Wu et al. (1984), Lee et al. (1991).
[2] Wu (1986).
[3] Wu (1989), Lee et al. (1991).
[4] Wu et al. (1984).

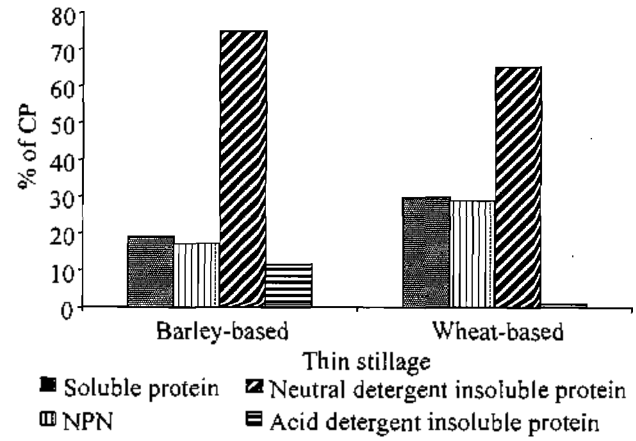

Figure 1. Protein fractions of wheat- and barley-based thin stillage (Adapted from Mustafa et al., 1999)

ether extract levels while corn thin stillage has the lowest CP and NDF levels (table 2). Due to the high hull content of barley grain, barley thin stillage has lower CP and higher ADF than wheat thin stillage. More than 60% of thin stillage CP is bound to the NDF while most of soluble protein is NPN (figure 1). The high levels of neutral detergent insoluble protein can in part explain the relatively high NDF content of thin stillage (table 2). Correcting for this protein, reduces the NDF content of wheat, barley, and rye thin stillage by 56, 44, and 49%, respectively (Mustafa et al., 2000b). Starch content for most types of thin stillage is low (table 2). However, some of the reported starch values for corn thin stillage are exceptionally high (table 2, Larson et al., 1993; Ham et al., 1994). This is likely due to differences in the distillation methods used.

The amino acid composition of a given cereal thin stillage is close to that of the original cereal grain (table 3). Glutamic acid is the most abundant amino acid in thin stillage followed by proline in wheat and barley thin stillage, and leucine in corn and sorghum thin stillage (table 3). The higher leucine levels for corn and sorghum thin stillage relative to that from wheat and barley thin stillage is due to the high leucine levels in corn and sorghum grains. In general, thin stillage derived from barley has a superior amino acid composition relative to wheat (Wu et al., 1984; Mustafa et al., 1999) and corn (Wu, 1986) thin stillage.

CHEMICAL COMPOSITION OF DISTILLERS' GRAINS

The main DM component of wet distillers' grains is carbohydrate (50 to 75%), of which less than 30% is non-structural carbohydrate (table 2). Distillers' grains derived from wheat and barley have a similar NDF content, which is higher than that of corn distillers' grains (table 2). However, barley distillers' grains are characterized by having a higher ADF content (Mustafa et al., 2000a). All distillers' grains contain low levels of starch, some of which is

Table 2. Chemical composition of thin stillage and distillers' grains relative to original grains (% DM basis)

	Wheat			Barley			Corn		
	Grain[1]	Thin stillage[2]	Distillers' grains[3]	Grain[1]	Thin stillage[2]	Distillers' grains[4]	Grain[1]	Thin stillage[5]	Distillers' grains[1,6]
Ash	2	8	4	3	10	4	1-2	7	5 (5)
EE	2	14	4	2	13	6	3-5	9	10 (10)
NDF	16	34	74	24	32	80	11-12	13	45 (50)
ADF	3	4	22	7	8	31	NA	NA	NA
CP	16	46	26	12	37	15	9-10	19	30 (30)
Starch	63	2	2	53	1	1	70	25	8 (6)
Total carbohydrates	80	32	64	82	40	75	84	65	55 (60)
Non-structural carbohydrates	65	28	7	64	38	4	77	NA	29 (33)

[1] Adapted from Sniffen et al. (1992), [2] Adapted from Mustafa et al. (1999), [3] Adapted from Ojowi et al. (1997).
[4] Adapted from Mustafa et al. (2000a), [5] Adapted from Ham et al. (1994).
[6] Values within parenthesis are for dried distillers' grains.

Table 3. Amino acid composition of thin stillage and distillers' grains relative to original cereal grains (% of DM)

	Wheat[1]			Barley[2]			Corn[3]			Sorghum[4]		
	Grain	TS[5]	DG[6]	Grain	TS	DG	Grain	TS	DG	Grain	TS	DG
Essential												
Arginine	5.7	4.9	7.6	5.7	4.8	5.5	5.8	5.6	5.7	4.1	6.2	3.9
Histidine	2.4	2.7	2.7	2.4	2.8	2.3	2.9	2.7	2.9	2.3	2.5	2.1
Isoleucine	3.4	3.4	3.8	3.4	3.2	4.0	3.2	4.0	3.9	5.0	3.3	4.3
Leucine	7.1	6.7	8.0	6.6	5.9	7.7	11.9	12.1	14.5	12.8	6.6	14.8
Lysine	2.8	2.9	3.9	4.0	4.4	3.9	3.1	3.6	2.9	2.4	6.1	1.9
Methionine	1.2	1.2	1.5	1.7	1.1	1.8	1.3	1.8	1.9	1.6	0.8	1.6
Phenylalanine	4.7	5.0	5.1	5.1	3.6	6.1	4.7	5.2	5.9	6.1	3.5	5.9
Valine	4.8	4.2	5.4	5.0	4.6	5.3	4.8	5.5	5.3	6.0	5.6	5.3
Non-essential												
Alanine	3.8	3.7	5.2	4.0	4.4	4.3	6.9	7.2	7.7	9.3	7.9	9.8
Aspartic	5.7	5.1	7.1	5.6	6.6	6.0	6.2	7.5	7.0	7.6	9.6	6.8
Glutamic	33.2	35.6	26.2	29.1	29.6	30.7	18.0	16.9	20.2	21.3	15.0	22.6
Glycine	4.4	4.8	5.4	3.8	7.0	3.7	3.7	4.2	3.9	3.6	7.7	3.0
Proline	11.2	12.8	9.8	9.6	12.3	11.1	8.8	8.2	9.5	8.4	7.0	9.0
Serine	5.0	3.5	5.7	4.2	5.4	4.2	4.6	5.1	5.5	4.9	5.6	4.8

[1] Adapted from Wu et al. (1984), [2] Adapted from Wu (1986), [3] Adapted from Wu (1989),
[4] Adapted from Wu and Sexson (1984).
[5] Thin stillage.
[6] Distillers' grains.

associated with yeast or microbial contamination.

Crude protein content varies considerably between and within different types of distillers' grains (table 2). In general, barley distillers' grains have the lowest CP content while wheat and corn distillers' grains have the highest (table 2). As with thin stillage, neutral detergent insoluble protein is the main protein fraction in distillers' grains (figure 2). However, the relative proportion of the other protein fractions varies from one type of distillers' grains to another. As with thin stillage, a considerable amount of the CP in distillers' grain is bound to the NDF fraction. Correcting for the associated CP, reduces the NDF content of wheat, rye, triticale and barley distillers' grains by 23, 22, 26, and 18%, respectively (Mustafa et al., 2000b).

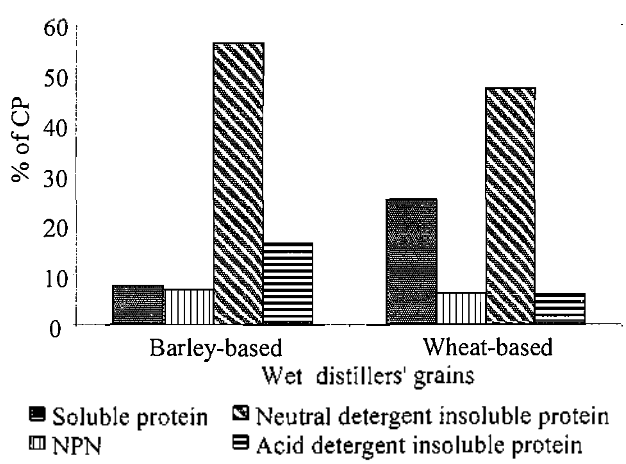

Figure 2. Protein fractions of wet wheat- and barley-based distillers grains (Adapted from Mustafa et al., 2000a)

Variations in CP content within each type of distillers' grains can be attributed to differences in fermentation process, cultivar of cereal grain, and the form in which the distillers' grains are marketed (alone or with solubles). For instance, wet distillers' grains derived from the fermentation of hard wheat have a higher CP content (32%) than distillers' grains derived from soft wheat (25%, Wu et al., 1984). Distillers' grains have a higher CP content than distillers' grains with solubles (Wu,1989; Lee et al., 1991). In several studies, the chemical composition of distillers' grains has been determined using laboratory-scale fermentors. The fermentation conditions in these studies may be different from those applied in large-scale or commercial facilities. This can explain the differences in chemical composition, particularly for protein, between commercially produced distillers' grains (Ojowi et al., 1997; Mustafa et al., 1999) and distillers' grains derived from laboratory-scale fermentors (Wu, 1986, 1989; Lee et al., 1991).

As with thin stillage, glutamic acid is the most abundant amino acid in distillers' grains (table 3). The amino acid profile of barley distillers' grains was found to be similar to that of barley grain while wheat distillers' grains had higher lysine, threonine and isoleucine levels than wheat (Wu et al., 1984). Wu (1986) indicated that barley distillers' grains have a superior amino acid profile than wheat distiller grains. Similarly, Mustafa et al. (2000a) reported higher amino acid concentrations for wet barley-based distillers' grains than wet wheat distillers' grains.

PROTEIN DEGRADABILITY AND RUMINAL BYPASS VALUE OF THIN STILLAGE

Protein degradability of thin stillage has only been determined *in vitro* (Mustafa et al., 1999; Iwanchysko et al., 1999; Mustafa et al., 2000b). This is due to the extreme fineness of thin stillage particles. *in vitro* protein degradability of thin stillage ranges from 70% for rye thin stillage to 48% for barley thin stillage (table 4). Thin stillage protein is characterized by its high degradation rate. The rate of degradation of wheat-based thin stillage ranged from 11.0 to 14.7 %/h compared with 4.9 to 5.5 %/h for canola meal (Mustafa et al., 1999; Iwanchysko et al., 1999). This is likely the main reason for the high *in vitro* ruminal degradability of thin stillage relative to other highly degradable protein sources (figure 3).

RUMINAL UNDEGRADED PROTEIN VALUE OF DISTILLERS' GRAINS

Traditionally, distillers' grains are considered a good source of ruminal undegraded protein (Aines et al., 1986; Ham et al., 1994; Boila and Ingalls, 1994). However, ruminal undegraded protein value of distillers grains is greatly affected by the level of heat input during drying, and by the level of thin stillage added to the distillers' grains (table 5). Drying has been known to increase ruminal undegraded protein content of distillers' grains (Boila and Ingalls, 1994). In contrast, studies at the University of Saskatchewan (Ojowi et al., 1997; Mustafa et al., 2000a) have shown that wet wheat distillers' grains are a relatively poor source of ruminal undegraded protein (table 5). Differences in ruminal undegraded protein content of distillers' grains due to drying are the result of increased levels of acid detergent insoluble protein. Some exceptions on the effects of drying on ruminal undegraded protein content of distillers' grains have been reported. Firkins et al. (1984) found no significant difference in the ruminal undegraded protein value between wet (47%) and dried (54%) corn distillers' grains. However, in that study, wet distillers' grains contained a higher level of acid detergent insoluble protein than dried distillers' grains.

Another factor affecting the ruminal undegraded protein value of distillers' grains is the type of cereal grain used as a fermentation substrate. Wet barley-based distillers' grains have a higher ruminal undegraded protein value than wet wheat distillers' grains (Mustafa et al., 2000a).

The effect of acid detergent insoluble protein on intestinal digestibility of ruminal undegraded protein of distillers' grains has been controversial. While several researchers (Van Soest, 1989; Sniffen et al., 1992) have suggested that acid detergent insoluble protein is entirely indigestible and does not contribute to the animals metabolizable protein pool, others (Nakamura et al., 1994a, b) have shown that acid detergent insoluble protein of dried distillers' grains is partially digestible. Nakamura et al. (1994a) found no difference in protein digestibility between distillers' grains samples with levels of acid detergent insoluble

Table 4. *In vitro* protein kinetic parameters and effective protein degradability of thin stillage derived from different cereal grains

	Thin stillage				
	Wheat	Rye	Barley	Triticale	SEM
Protein kinetic parameters					
Soluble fraction (% of CP)	28.8^{c}	44.5^{a}	19.0^{d}	35.0^{b}	0.38
Slowly degradable (% of CP)	43.1^{a}	30.6^{c}	44.9^{a}	37.9^{b}	0.92
Degradation rate (%/h)	14.2^{a}	11.5^{b}	9.3^{c}	14.9^{a}	0.4
Effective degradability (%)	60.8^{c}	65.9^{a}	48.2^{d}	63.2^{b}	0.59

^{a,b,c,d} Means in the same row with different superscripts differ ($p<0.05$).

Adapted from Mustafa et al. (2000b).

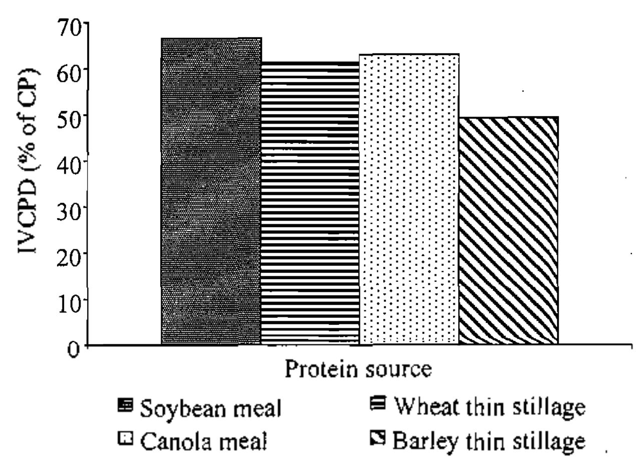

Figure 3. *In vitro* crude protein degradability (IVCP D) of wheat- and barley-based thin stillage relative to soybean and canola meal (Adapted from Mustafa et al., 1999)

Table 5. Ruminal undegraded protein (RUP) and acid detergent insoluble protein (ADICP) content of distillers' grains

	RUP (% of CP)	ADICP (% of CP)	Reference
Wet wheat distillers' grains[1]	31-38	5.9	Ojowi et al. (1996); Mustafa et al. (2000)
Dried wheat distillers' grains[1]	51-59	9.7-16.7	Boila and Ingalls (1994)
Barley-based wet distillers' grains[1]	38.4	16.2	Mustafa et al. (2000a)
Wet wheat distillers' grains[1,2]	46.0	4.6	Mustafa et al. (2000b)
Wet barley distillers' grains[1,2]	50.8	14.7	Mustafa et al. (2000b)
Wet rye distillers' grains[1,2]	45.9	6.5	Mustafa et al. (2000b)
Wet triticale distillers' grains[1,2]	48.8	6.2	Mustafa et al. (2000b)
Wet corn distillers' grains[3]	55	7.3	Ham et al. (1994)
Wet corn distillers' grains[3]	47	15.6	Firkins et al. (1984)
Dried corn distillers' grains[3]	63.2-67.8	11.3-23.8	Nakamura et al. (1994)
Dried corn distillers' grains[3]	54	12.3	Firkins et al. (1984)
Dried corn distillers' grains plus solubles[3]	38-49.4	5.9-14.8	Ham et al. (1994)

[1] Estimated as 100-ruminal degradability.
[2] Washed distillers' grains.
[3] Estimated as remaining crude protein after 12 h of ruminal incubation.

protein ranging from 8 to 28% of CP. However, due to the reduction in metabolizable lysine content, digestible acid detergent insoluble protein from heat-damaged distillers' grains is poorly utilized for growth by ruminants (Nakamura et al., 1994b).

FIBER DEGRADABILITY AND DIGESTIBILITY OF DISTILLERS' GRAINS

For many byproduct feeds, a high fiber content has been considered a disadvantage due to the low digestibility of fiber. However, this is not the case for distillers' grains (table 6). Following 24 h of ruminal incubation, about 77% of dried corn distillers' grains NDF were degraded in the rumen (Varga and Hoover, 1983). This compares with 48% for wheat barn with a similar NDF content. Similar results were also reported by Firkins et al. (1985) who reported a ruminal NDF degradability of 77 and 79% for wet and dried corn distillers' grains, respectively, following 36 h of ruminal incubation.

Ruminal degradability of wet wheat distillers' grains was determined relative to wet brewers' grains by Ojowi et al. (1997). The authors reported higher ruminal NDF degradability for distillers' grains (46%) than for brewers' grains (38%, Ojowi et al., 1996). This was despite the higher rate of degradation of NDF in brewers' grains (4.5 %/h) than in distillers' grains (2.7 %/h). Wet barley-based distillers' grains have a lower ruminal degradability of NDF relative to other distillers' grains due to their high hull content (Mustafa et al., 2000a).

Total tract fiber digestibility of distillers' grains is also high. This is evident by the high total tract NDF digestibility reported for dried barley-based distillers' grains (70 to 80%) as reported by Weiss et al. (1989). Ham et al. (1994) determined total tract NDF digestibility of corn distillers' byproducts in a metabolism trial where the byproducts replaced 40% of dry rolled corn. Steers fed a wet distillers' grain-based

Table 6. Ruminal degradability of neutral detergent fiber of distillers' grains

	Degradation rate (%/h)	Degradability[1] (%)	Reference
Wet wheat distillers' grains	2.7-3.1	38.3-45.4	Ojowi et al. (1997); Mustafa et al. (2000a)
Wet barley-based distillers' grains	3.3	36	Mustafa et al. (2000a)
Washed wet wheat distillers' grains	5.2	45.0	Mustafa et al. (2000b)
Washed wet barley distillers' grains	3.8	34.2	Mustafa et al. (2000b)
Washed wet rye distillers' grains	7.6	47	Mustafa et al. (2000b)
Washed wet triticale distillers' grains	4.2	43.9	Mustafa et al. (2000b)
Wet corn distillers' grains	4.4	NA	Firkins et al. (1985)
Dried corn distillers' grains[2]	7.2	76.6	Varga and Hoover (1983)

[1] Effective degradability calculated according to Ørskov and McDonald (1979).
[2] Degradability expressed as a percentage of NDF that disappeared in 24 h.

diet had a higher NDF digestibility (70%) than steers fed the control (63%) or a corn gluten feed-based diet (63%). Unlike protein digestibility, NDF digestibility of distillers' grains appears to be less affected by the type of grain used in the fermentation process or by the drying process used. Using cross-bred lambs, Lodge et al. (1997) determined total tract nutrient digestibility for sorghum distillers' byproducts relative to corn distillers' byproducts. While sorghum distillers' byproducts exhibited reduced CP and OM digestibility relative to corn distillers' byproducts, total tract digestibility of NDF was similar.

EFFECTS OF FEEDING THIN STILLAGE ON BEEF CATTLE PERFORMANCE

Thin stillage can be fed as is (Ojowi et al., 1996; Fisher et al., 1999), diluted with water (Fisher et al., 1999) or condensed (Rust et al., 1990). It can also be fed in combination with distillers' grains (Larson et al., 1993; Ham et al., 1994). The feeding value of thin stillage is influenced by the form in which it is provided. Maximum efficiency is expected when thin stillage completely replaces water as a drinking source (Rust et al., 1990). The intake of thin stillage by cattle varies depending on diet quality and environmental conditions. Ojowi et al. (1996) reported a 28% higher consumption of thin stillage than water by steers grazing crested wheatgrass in the summer season. However, for steers fed balanced diets, during growing and finishing periods under a controlled environment (16℃), thin stillage consumption was similar to that of water (Fisher et al., 1999).

The positive response of feeding thin stillage to beef cattle has been reported by several workers (table 7). Ruminal infusion of corn thin stillage as a replacement for 20% of corn in the diet was found to improve OM, NDF, and starch digestibility (Ham et al., 1994). Cattle grazing crested wheatgrass with access to wheat thin stillage gained 53% better than cattle with access to water (Ojowi et al., 1996). The most likely explanation for the improved performance is that, under conditions where the pasture was limiting in terms of nutrient quantity and quality, thin stillage acted as an energy and protein supplement and thereby contributed to the animal's requirements for growth.

When offered with balanced growing and finishing diets, thin stillage improves feed efficiency by reducing DMI without affecting daily gain (table 7). Fisher et al. (1999) reported 32 and 27% improvement in feed efficiency (DMI/gain) for steers during the growing and finishing periods, respectively. The improvement was primarily due to a 24 and 16% reduction in DMI of the basal diet during the growing and finishing periods, respectively. When both thin stillage and feed DMI was considered, there was no effect of treatment on feed efficiency. The authors also found that the improvement in feed efficiency was directly related to the DM content of thin stillage. The higher the DM content of thin stillage, the greater the reduction in feed DMI.

Rust et al. (1990) studied the effects of feeding condensed corn distillers' solubles to steers. The authors found that steers offered condensed distillers' solubles as the sole fluid source obtained 20% of their daily DMI from condensed distillers' solubles and were more efficient in converting feed to gain than steers with access to water. The authors attributed the improved feed efficiency obtained with condensed distillers' solubles to a 13.3% reduction in DMI.

Reasons for the improved performance of cattle offered thin stillage as a fluid source are not clear. Hanke et al. (1983) suggested that enhanced performance may be due to high levels of trace elements in thin stillage or to changes in ruminal carbohydrate and protein digestion. Despite its low pH (4), feeding thin stillage to cattle does not seem to have any detrimental effects on ruminal metabolism (Iwanchysko et al., 1999).

Evidence collected to date, indicates that thin stillage provides a balanced source of ruminal degraded and undegraded protein. High ruminal degradability of the thin stillage protein that enters the rumen provides optimal levels of ammonia nitrogen to ensure maximum microbial yield (Iwanchysko et al., 1999). Furthermore, there is evidence that approximate-

Table 7. Performance of steers offered thin stillage or water as a fluid source

	Treatment		
	Thin stillage	Water	SEM
Steers grazing crested wheatgrass[1]			
Fluid intake (L/d)	48.2[a]	28.9[b]	1.1
ADG (kg)	1.4[a]	0.9[b]	0.1
Steers fed growing diets[2]			
Fluid intake (L/d)	23.9	22.9	1.77
ADG (kg)	1.6	1.6	0.11
Gain:feed[4]	0.3	0.2	0.01
Steers fed finishing diet[3]			
Fluid intake (L/d)	26.9	27.0	2.97
ADG (kg)	1.6	1.4	0.11
Gain:feed[4]	0.19	0.15	0.01

[a,b] Means in the same row with different superscripts are different ($p<0.05$).

[1] Adapted from Ojowi et al. (1996).

[2,3] Adapted from Fisher et al. (1999).

[4] Linear improvement in gain:feed ratio detected as thin stillage DM content increased.

ly 50% of the thin stillage consumed bypasses rumen fermentation either via the esophageal groove or by failure to equilibrate with rumen fluid (Iwanchysko et al., 1999). Larson et al. (1993) estimated that for a steer consuming 35 L/d of corn thin stillage, 0.8 kg of thin stillage DM will be available for enzymatic digestion in the small intestine. This shift in digestion to the small intestine is expected to improve performance as digestion in the small intestine is energetically more efficient than ruminal fermentation.

EFFECTS OF FEEDING DISTILLERS' GRAINS ON DAIRY CATTLE PERFORMANCE

Distillers' grains have been recognized as a source of both energy and protein. Replacing a portion of the concentrate mix with wet or dried distillers' grains is an effective way of increasing ruminal undegraded protein and fermentable fiber content of dairy diets. However, the production response of dairy cows is greatly influenced by the quality of distillers' grains.

Feeding dried corn distillers' grains plus solubles with high acid detergent insoluble protein (33% of CP) to dairy cows in early lactation at 22.5 and 41.6% of the diet DM, reduced milk yield by 10% and milk protein percentage by 8% (Van Horn et al., 1985). However, feeding dried barley-based distillers' grains with a higher acid detergent insoluble protein content (39% of CP) at a lower inclusion rate (13% of the diet DM) to dairy cows in mid to late lactation had no effect on milk yield or composition (Weiss et al., 1989).

The adverse effect of heat-damaged distillers' grains on the performance of dairy cows is mainly due to the low availability of specific amino acids such as lysine, threonine, arginine and alanine (Palmquist and Conrad, 1982). However, because it is the most heat-sensitive amino acid, lysine would probably be the first limiting amino acid for cows fed dried distillers' grains. The effects of added lysine on the performance of dairy cows fed dried corn distillers' grains were investigated by Armentano (1994). The study showed that cows fed diets containing 13% dried corn distillers' grains and supplemented with blood meal (7.9% lysine) outperformed cows fed a similar insonitrogenous diet containing 18% dried corn distillers' grains. In another study, Armentano (1996) showed that supplementing a dairy diet containing 18% dried corn distillers' grains with up to 48 grams of fat-protected lysine, significantly increased milk yield.

EFFECTS OF FEEDING DISTILLERS' GRAINS ON BEEF CATTLE PERFORMANCE

Distillers' grains have been used in feedlot diets as a source of protein and/or energy. The feeding value of wet wheat distillers' grains as a protein source for growing beef cattle was investigated by Ojowi et al. (1997). Diets were formulated where canola meal was replaced by wet wheat distillers' grains or wet brewers grains. Feeding wet wheat distillers' grains (13.4% of DM) improved ($p<0.05$) ADG of steers over those fed a barley-based diet supplemented with canola meal (1.57 vs 1.41 kg) for the first 56 d of the growing period. However, differences were not apparent after 84 d or during the finishing phase (table 8).

The majority of research on the feeding value of distillers' grains as an energy source has been conducted with corn distillers' grains. Several researchers have shown that the energy value of corn distillers' grains is superior to that of corn (table 9). In general, wet distillers' grains have a higher energy value than dried distillers' grains and the addition of thin stillage improves the energy value of distillers' grains. Firkins et al. (1985) conducted a finishing trial to determine the energy value of wet corn distillers' grains for steers. The byproduct was fed at 0, 25 and 50% of the diet DM replacing corn. Daily gain and feed efficiency tended to improve linearly as the inclusion rate of distillers' grains in the diet increased. Larson et al. (1993) fed wet corn distillers' grains plus solubles to finishing calves and yearlings. When fed to calves at 5.2, 12.6, and 40% of the diet DM, wet corn distillers' grains plus solubles contributed 17, 33, and 29% more net energy for gain, respectively than dry-rolled corn when fed to calves. The corresponding values for yearlings were 80, 62, and 47%, respectively. In a more recent study, Ham et al.

Table 8. Effects of feeding wet wheat distillers' grains on steer performance

	Treatment			
	Control	Wet distillers' grains[1]	Wet brewers' grains[2]	SEM
Growing period (d 1 to 84)				
DMI (kg/d)	9.5	9.7	9.1	0.28
ADG (kg)	1.3	1.4	1.4	0.05
Feed:gain	7.5	7.2	6.8	0.30
Finishing period (d 84 to slaughter)				
DMI (kg/d)	10.5	10.9	10.1	0.41
ADG (kg)[3]	1.4	1.32	1.25	0.05
Feed:gain	7.5	8.3	8.1	0.45

[1] Inclusion rate of 13.4 and 4.7% in the growing and finishing periods, respectively.

[2] Inclusion rate of 16.7 and 5.7% in the growing and finishing periods, respectively.

[3] ADG greater for control than wet brewers' grains ($p< 0.05$).

Adapted from Ojowi et al. (1997).

Table 9. Effect of corn distillers' grains on feed efficiency of cattle relative to corn

Distillers' grains	Inclusion rate (% in diet)	Improvement over corn	Reference
Wet corn distillers' grains	5.2, 12.6, 40	5, 10, 20%	Larson et al. (1993)
Wet corn distillers' grains	50, 75	12, 11%	Farlin (1981)
Dried corn distillers' grains plus solubles	40	16%	Ham et al. (1994)
Wet sorghum distillers' grains	40	0%	Lodge et al. (1997)
Dried sorghum distillers' grains plus solubles	40	-7.2%	Lodge et al. (1997)

(1994) found that replacement of dry rolled corn with wet or dried corn distillers' grains up to 40% of the diet DM improved ADG and feed efficiency of finishing steers. At the 40% inclusion rate, net energy for gain for wet and dried distillers' grains were 139 and 121%, respectively higher than that of corn.

The effect of acid detergent insoluble protein content of corn distillers' grains on cattle performance has been studied by Ham et al. (1994). The authors found that feeding dried corn distillers' grains with a low (5.9% of CP), an intermediate (13.9% of CP), and a high (14.8% of CP) level of acid detergent insoluble protein had no effect on efficiency of gain by growing steers. However, the levels of acid detergent insoluble protein in the study of Ham et al. (1994) were much lower than those (23.8 to 32.9% of CP) reported in other studies for heat damaged corn distillers' grains (Van Horn et al., 1985; Nakamura et al., 1994a, b). These results suggest that dried distillers' grains with an acid detergent insoluble protein level up to 15% of CP is not likely to have any detrimental effect on performance of growing ruminants.

The energy value of distillers' grains is also affected by the type of cereal grain from which the distillers' grains are derived. Lodge et al. (1997) evaluated sorghum distillers' byproducts for finishing cattle relative to dry-rolled corn. Cattle fed wet sorghum distillers' grains or wet sorghum distillers' grains plus solubles were similar in efficiency to those fed dry-rolled corn. However, steers fed dried sorghum distillers' grains plus solubles were less efficient than steers fed the other treatments. Based on steer performance, these authors estimated the net energy for gain for wet sorghum distillers' grains, wet sorghum distillers' grains plus solubles, and dried sorghum distillers' grains plus solubles to be 96, 102, and 80% of that of corn. The results of that study confirm the findings of an earlier study (Ham et al., 1994) which showed lower energy value for dried distillers' grains relative to wet distillers' grains.

In many studies, distillers' grains were used to replace corn. Despite the fact that such replacement, considerably reduced the starch content of the diets, cattle fed distillers' grain-based diets were more efficient than those fed the corn-based diets (Larson et al., 1993; Ham et al., 1994). Several reasons have been suggested in an attempt to explain the improved performance of cattle as a result of feeding distillers' grains. Improved feed efficiency when feeding distillers' grains may be in part due to reduced subacute acidosis, which will reduce gain and efficiency (Firkins et al., 1985; Larson et al., 1993). However, results from the study of Ham et al. (1994) do not support this hypothesis. These authors found no differences in ruminal pH or volatile fatty acid concentrations between steers fed dry-rolled corn or wet corn distillers' grains. Ham et al. (1994) suggested that a higher fat content and a shift in organic matter digestibility to the small intestine in wet and dried distillers' grains accounted in part for the higher net energy value for gain of wet and dried corn distillers' grains relative to corn.

A large part of the improved cattle performance can be attributed to the high ruminal (Ojowi et al., 1997; Mustafa et al., 2000) and total tract (Ham et al., 1994; Lodge et al., 1997) digestibility of distillers' grains. Reasons for the high quality of distillers' grains fiber are not well understood. High cell wall digestibility of distillers' grains can in part be attributed to the high levels of protein associated with NDF. This fraction of NDF is readily available for ruminal fermentation and intestinal digestibility (Sniffen et al., 1992). More detailed studies are needed to identify the cell wall monomers (i.e. uronic acid, neutral sugars, and phenolic monemers) of distillers' grains. It has been shown that some of cell wall monomers are more digestible (galactose and uronic acid) than others (xylose and ρ-coumaric acid, Bourquin et al., 1990; Bourquin and Fahey, 1994).

CONCLUSIONS

Distillers' byproducts have been recognized as excellent energy and protein sources for growing and lactating cattle. Thin stillage can be used as a partial or complete replacement of water. When fed with poor quality feeds, thin stillage acts as an energy and protein supplement. However, in well balanced diets (growing and finishing diets), thin stillage improves feed efficiency by reducing feed DMI. Distillers' grains can be fed to dairy cows at up to 20% of the diet. Consideration should be given to lysine supplementation of diets containing dried corn distillers' grains. For beef cattle, corn distillers' grains have an energy value that is equal to or superior to corn. Limited research on wet wheat distillers' grains indicates that partial replacement of barley in growing and finishing diets with distillers' grains results in similar performance to barley-fed cattle. More research is needed to identify the energy value of distillers' grains derived from cereal grains other than corn.

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