Animal Feed Science and Technology 159 (2010) 122–130

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Sources of variation in composition of DDGS

R.L. Belyea[a,*], K.D. Rausch[b], T.E. Clevenger[c], V. Singh[b], D.B. Johnston[d], M.E. Tumbleson[c]

[a] Department of Animal Sciences, University of Missouri, 920 East Campus Drive, Columbia, MO 65211, United States
[b] Department of Civil Engineering, University of Missouri, Columbia, MO 65211, United States
[c] Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, United States
[d] Food Technologist, USDA-ARS, ERRC, Wyndmoor, PA, United States

ARTICLE INFO

Article history:
Received 23 July 2009
Received in revised form 10 June 2010
Accepted 21 June 2010

Keywords:
Composition
DDGS
Dry grind processing
RUP
Variation

ABSTRACT

High protein and high energy content make distillers dried grains with solubles (DDGS) a unique ingredient for ruminant diets, but variation in composition reduces nutritional quality and market value. There is little published information that addresses the specific causes of variation. Samples of DDGS from dry grind processing (ethanol) plants in the upper Midwest were analyzed for nutrient concentrations and sources of variation were evaluated.

Significant plant × period (time) interactions indicated that variation was associated with specific fermentation batches, rather than plants or time (periods) *per se*. Differences in maize characteristics and in processing conditions probably were responsible for batch to batch effects. Fat content of DDGS samples was relatively uniform, but there was considerable variation in protein concentration (260–380 g/kg DM). Low lysine (8.9 g/kg DM) and elevated pepsin insoluble (bound) protein concentrations were additional concerns. Published values for ruminally undegradable protein content were as accurate as estimates using specific plant data.

1. Introduction

Maize is converted to ethanol by two main technologies—dry grind processing and wet milling (Rausch and Belyea, 2006). In wet milling, the maize kernel is fractionated into starch and other components, and starch is converted into ethanol; wet milling requires significant amounts of equipment and capital. In dry grind processing, the whole (unfractionated) maize kernel is used as a substrate for fermentation, requiring less equipment and capital. In both processes, unfermented residual material is converted into distillers dried grains with solubles (DDGS). DDGS are used mainly in ruminant diets and are valuable because of high concentrations of energy (due to high fat content), protein and ruminally undegradable protein (RUP).

The composition of DDGS can be quite variable (Belyea et al., 1989, 2004; Shurson et al., 2001), which makes precise diet formulation difficult. When diets are formulated to contain DDGS, average protein concentration often is assumed. Actual protein content could be greater than average, resulting in excess protein intake or less than average, resulting in protein deficiency. Protein deficiency can reduce animal productivity, while excess protein can result in protein wastage (from increased nitrogen excretion in feces and urine) and in adverse physiological responses. There is little published information

Abbreviations: ADF, acid detergent fiber; DDGS, distillers dried grains with solubles; EAA, essential amino acids; NDF, neutral detergent fiber; RUP, ruminally undegradable protein.

* Corresponding author. Tel.: +1 573 882 6654; fax: +1 573 882 6827.
E-mail address: belyear@missouri.edu (R.L. Belyea).

0377-8401/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.anifeedsci.2010.06.005

that addresses causes of variation. This information could help to provide the basis for strategies to reduce variation and improve quality of DDGS. The objective was to identify and evaluate sources of variation in the composition of DDGS and determine effects on nutritional quality.

2. Materials and methods

2.1. Sample collection

Samples of DDGS and corresponding maize samples were obtained from nine dry grind ethanol plants located in the upper Midwest. Maize was grown by local producers and presumably reflected a variety of soils, climatic conditions and hybrids. Dry grind processing is a batch type fermentation method (Rausch and Belyea, 2006). The length of time from the initial step (grinding of maize) to the last step (drying of DDGS) can vary from 60 to 90 h, depending on processing conditions. Each fermentation batch remains separated from other batches and retains its unique characteristics until DDGS are placed in storage facilities. The characteristics of each sample of DDGS reflect a specific batch of maize and processing conditions. Fermentation equipment and processing conditions generally were similar among the ethanol plants. When processing conditions at a particular plant were aberrant (*i.e.*, increased pH in the fermentation tank), sampling was delayed until conditions returned to normal. In actuality, this occurred only a few times.

Samples of maize and DDGS (about 0.5 kg each) were taken at each processing plant during four different periods (fall, winter, spring and summer); within each period, samples were taken during each of three successive weeks, frozen and shipped to the University of Missouri for analytical measurements. A total of 108 samples (9 plants × 4 periods × 3 weeks per period) were obtained.

2.2. Analytical methods

Maize and DDGS samples were ground to pass a screen with 2.0 mm diameter openings. Analytical dry matter was determined by method 934.01 (AOAC, 1997).

NDF concentrations were determined according to Van Soest et al. (1991); sodium sulfate and heat stable amylase were not used, and there was no correction for residual ash. ADF was determined by method 978.13 (AOAC, 1997) and was exclusive of residual ash. N was measured by thermoelectric conductivity (method 968.06, AOAC, 1997) using a FP-428 N Determinator (Leco Corp., St. Joseph, MI); total protein was estimated as N × 6.25. Buffer soluble N was determined using the method of Krisnamoorthy et al., 1982; buffer soluble protein (rapidly degraded or immediately soluble protein fraction) was estimated as soluble N × 6.25. Pepsin insoluble N was determined according to Goering et al. (1972); pepsin insoluble protein (estimate of bound protein) was calculated as pepsin insoluble N × 6.25. Ash was measured using method 942.05 (AOAC, 1997). Fat was determined by method 920.39 (AOAC, 1997). A subset of 16 samples of DDGS was selected from the four periods; essential amino acid (EAA) concentrations were determined in these samples and in corresponding maize samples using method 982.3 (AOAC, 1997).

2.3. N disappearance measurements

N disappearance data were determined following the *in situ* method of Stern and Satter (1984). Subsamples (2.0 g) of each DDGS sample were placed in triplicate *in situ* digestion bags (Ankom, 2 cm × 6 cm, 50 μm pore size); sets of samples were digested for 6, 12 or 24 h in the rumens of two lactating, fistulated dairy cows consuming a conventional diet. Sets of bags were removed at the appropriate time, rinsed thoroughly and dried at 105 °C for 24 h. Dried bags were weighed so that dry matter remaining could be calculated. A sample of residue was removed from each bag, and N content was determined as described previously. N remaining was calculated as:

$$\text{N remaining (g/kg N)} = \frac{\text{g N in residue}}{\text{g N in original sample}} \times 1000$$

N disappearance rates were determined by regression of N remaining upon digestion time using a simple linear regression procedure. Ruminally undegradable protein (RUP) is the fraction of protein in a feed ingredient that is not degraded in the rumen. The amount of N remaining at 24 h was used to estimate RUP (RUP = N remaining at 24 h × 6.25). For comparison purposes, N disappearance equations were calculated for each processing plant from their specific data; in addition, an overall (across plants) equation also was calculated. RUP concentrations then were estimated using the plant-specific equations and the overall equation.

2.4. Statistical analyses

Compositional data were analyzed for effects of plant, period and period × plant using a general linear model (SAS, 2003). Means were compared for effects that were significant ($P<0.01$). N disappearance data were analyzed using a mixed model (SAS, 2003); the model included effects for period, week, digestion time; period × week, week × digestion time and week × period × digestion time. Means were compared when effects were significant ($P<0.01$).

Table 1
Effects of plant and period on mean fiber, fat and ash concentrations (g/kg DM) in samples of distillers dried grains with solubles.

Effect	NDF[a]	ADF[b]	Fat	Ash
Plant				
1	605.7	241.7	112.1	35.3
2	576.4	236.2	120.5	41.2
3	587.5	236.2	109.1	38.6
4	585.5	229.7	118.0	40.1
5	612.5	243.6	119.2	36.7
6	576.8	245.4	115.6	40.7
7	590.2	241.4	121.3	42.9
8	597.5	243.8	107.9	38.0
9	565.0	222.2	115.0	40.9
LSD[c]	4.6	NS[d]	NS[d]	0.7
SE[e]	9.2	4.2	3.9	0.7
Period				
1	555.6	227.2	121.7	39.2
2	620.9	251.6	109.1	38.2
3	609.5	241.5	114.7	39.4
4	558.2	228.5	116.9	40.6
LSD[c]	19.0	7.1	2.1	0.4
SE[e]	6.3	2.8	2.6	0.5
Overall mean	588.9	237.3	115.2	39.3

[a] Neutral detergent fiber.
[b] Acid detergent fiber.
[c] Least significant difference (P<0.01).
[d] Effect not significant.
[e] Standard error.

3. Results

3.1. Compositional data

There were effects (P<0.01) of plant and period on fiber and ash concentrations (Table 1). Plants 1 and 5 had the highest NDF concentrations (605.7 and 612.5 g/kg DM, respectively), while plant 9 had the lowest (565.0 g/kg DM). All five constituents were affected (P<0.01) by period (Table 1). Fiber concentrations (NDF and ADF) were higher in periods 2 and 3 than periods 1 and 4; fat concentration was highest in period 1, while ash concentration was highest in period 4.

There were effects (P<0.01) of plant on the concentrations of protein constituents and characteristics (Table 2). Total protein and soluble protein concentrations were not different among plants. Pepsin insoluble protein concentration was highest (P<0.01) for plants 3 and 8 (246.9 and 250.6 g/kg total protein), while plant 9 had the lowest (196.4 g/kg total protein). RUP content was greatest (P<0.01) for plant 8 (495.2 g/kg total protein) and lowest for plant 9 (408.2 g/kg total protein). Periods affected protein constituents (Table 2); total protein was highest in period 2 and lowest in period 4. Pepsin insoluble protein was higher (P<0.01) in periods 3 and 4 than periods 1 and 2; RUP concentrations were highest in period 3.

For many nutrient concentrations, there were significant (P<0.01) plant × period interactions; these provide a more relevant view of variation in composition over time than main effects. Fig. 1 shows the plant × period interactions for total protein and fat concentrations, while Figs. 2 and 3 show interactions for RUP and pepsin insoluble protein concentrations, respectively. These data show how wide the range in concentrations can be. For example, the range in concentration for total protein was about 260–380 g/kg DM, compared to the mean concentration (320.4 g/kg DM, Table 2). Likewise, for fat, concentrations ranged from about 50 to about 150 g/kg DM, compared to a mean of 115.2 g/kg DM (Table 1). Variation was from 250 to 750 g/kg total protein and from 150 to 400 g/kg total protein for RUP and pepsin insoluble protein, respectively.

3.2. N disappearance measurements

There were significant (P<0.01) plant × period interactions for N disappearance. It would be difficult to present and discuss effects for all plant × period combinations, because of the large amount of data. The data for plant 1 (Table 3) are representative and can be used for illustration purposes. For plant 1, there was considerable variation in N disappearance within and across periods at each digestion end point. For example, in period 1, the 6 h means were not different among weeks (791, 782 and 717 g N remaining/kg N). In period 2, the 6 h means for week 1 were different (P<0.01) from the means for weeks 2 and 3. In period 3, 6 h disappearance means were different in all three weeks. In period 4, means for week 1 and 3 were different from each other but not from week 2. Similar patterns existed for N disappearance at 12 and 24 h. The amount of N remaining decreased as digestion time increased, as would be expected. Generally, means at 12 h were less (P<0.01) than 6 h means, and 24 h means were less than 12 h means (Table 3). However, there were exceptions. For example, in period 1, mean N disappearance at 12 h was not different from the 6 h mean (701 g N remaining/kg N *vs* 717 g

Table 2
Effects of plant and period on mean concentrations of protein constituents in samples of distillers dried grain with solubles.

Effect	Total protein (g/kg DM)	Soluble protein g/kg total protein	Pepsin insoluble protein g/kg total protein	Ruminally undegradable protein[a] g/kg total protein
Plant				
1	317.5	138.6	225.3	471.8
2	324.4	137.2	227.6	438.1
3	309.2	158.5	246.9	436.2
4	321.5	166.6	228.2	436.6
5	322.6	134.9	226.9	453.1
6	324.8	174.9	227.1	455.7
7	322.1	174.3	224.3	441.9
8	323.2	158.4	250.6	495.2
9	323.6	155.6	196.4	408.2
LSD[b]	NS[c]	NS[c]	4.3	40.5
SE[d]	5.6	14.2	9.4	8.6
Period				
1	315.2	154.8	205.8	361.7
2	338.4	152.8	207.1	462.7
3	328.0	168.5	246.3	501.3
4	300.1	145.7	253.3	468.5
LSD[b]	10.1	NS[c]	15.2	32.0
SE[d]	3.7	9.4	6.4	5.6
Overall mean	320.4	155.8	227.6	449.4

[a] N remaining 24 h × 6.25.
[b] Least significant difference (P<0.01).
[c] Effect not significant.
[d] Standard error.

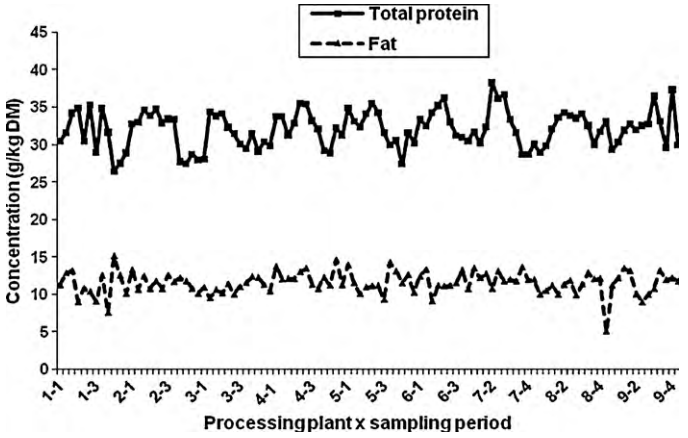

Fig. 1. Effects of processing plant × sampling period on total protein and fat concentrations of samples of distiller dried grains with solubles.

N remaining/kg N). In period 2, mean disappearance at 24 h was not different from 12 h (470 g N remaining/kg N *vs* 533 g N remaining/kg N).

4. Discussion

There are few published reports that quantify variation in composition of DDGS from dry grind processing. Shurson et al. (2001) characterized 118 samples from 10 plants taken over a three-year period (1997–1999) in the upper Midwest. Some samples were taken from the same plants in our study, which occurred later (2000–2001). Data from these two studies generally were similar (Table 4). Mean fat and protein concentrations (109 and 302 g/kg DM) from Shurson et al. (2001) were similar to our data (115 and 320 g/kg DM, respectively). In our study, the coefficient of variation for fat (17.7%) was higher than reported by Shurson (7.8%), while for protein concentrations, coefficients of variation were similar (7.7% *vs* 6.4%). Shurson et al. (2001) reported high coefficients of variation (51.8% and 54.2%) for ADF concentrations of DDGS from two plants; otherwise, variation was similar for the two studies. In our study, mean ADF concentration was higher than reported by Shurson (237 g/kg DM *vs* 162 g/kg DM). We also found higher NDF concentrations than reported in their study. The reason for differences in fiber concentrations between the two studies is not evident.

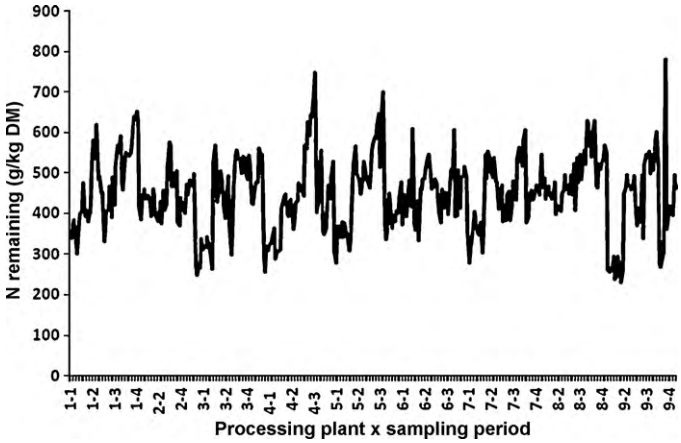

Fig. 2. Effects of processing plant × sampling period on ruminally degradable protein concentrations of samples of distillers dried grains with solubles.

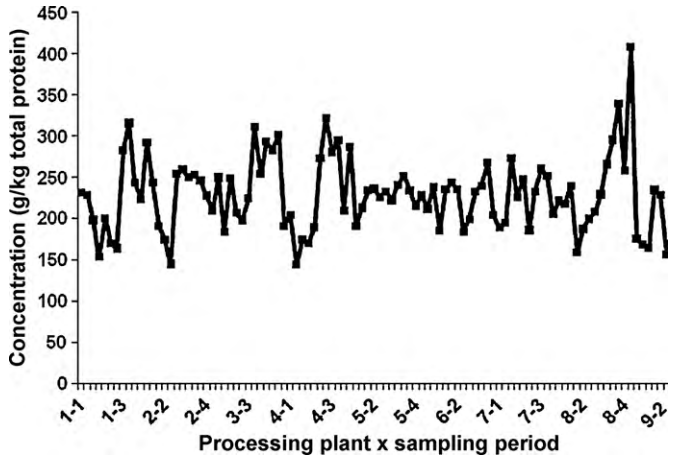

Fig. 3. Effects of processing plant × sampling period on pepsin insoluble protein concentrations of samples of distillers dried grains with solubles.

There is little published information on the underlying causes of variation in composition of DDGS. Interactive effects of plant × period in the present study indicated that fermentation batches were more important sources of variation than plants or periods. Variation among batches could be due to differences in composition or physical form of ground maize or to deviations in processing conditions. Maize starch consists of amylopectin and amylose polymers. Amylopectin to amylose

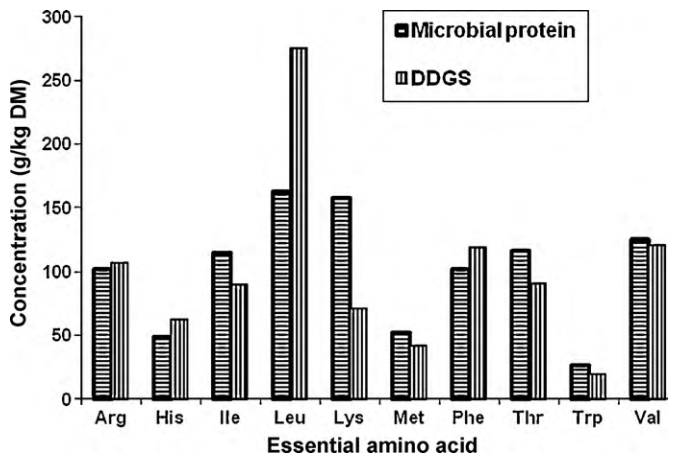

Fig. 4. Comparison of essential amino acid concentrations of distillers dried grains with solubles (DDGS) and ruminal microbial protein.

Table 3
N disappearance[a] data by period and week for plant 1[b].

Period	Week	Digestion time (h)		
		6	12	24
1	1	791	687	364
	2	782	685	354
	3	717	701	421
2	1	652	453	365
	2	773	684	568
	3	715	533	470
3	1	531	468	381
	2	648	551	442
	3	852	684	558
4	1	784	685	505
	2	823	711	553
	3	898	819	637

[a] Mean g N remaining/kg total N.
[b] LSD = 84.8 for all comparisons.

Table 4
Comparison of variation in composition[a] of distillers dried grains with solubles from dry grind processing plants.

Plant	Shurson et al. (2001)						Plant	Present study					
	ADF[b]		Fat		Protein			ADF		Fat		Protein	
	Mean	CV[c]	Mean	CV	Mean	CV		Mean	CV	Mean	CV	Mean	CV
1	142	8.0	102	10.5	308	10.2	1	242	4.0	112	19.1	313	9.7
2	181	7.5	107	6.1	309	10.2	2	236	3.2	118	7.4	324	8.1
3	148	51.8	112	5.0	301	7.7	3	232	2.8	109	8.0	309	7.6
4	138	na[d]	114	5.5	314	2.1	4	230	5.9	120	8.7	322	7.1
5	160	4.9	117	7.4	290	3.3	5	243	4.3	119	14.1	323	7.2
6	158	8.4	102	9.1	307	6.8	6	245	2.8	115	11.2	326	7.2
7	163	54.2	114	7.0	287	5.7	7	241	5.6	121	8.6	322	5.5
8	185	10.1	108	4.4	316	4.9	8	244	2.8	108	18.6	323	5.5
9	154	11.2	107	5.9	287	4.1	9	222	5.1	115	17.7	323	7.9
10	171	6.6	108	5.5	295	3.3	–	–	–	–	–	–	–
Mean	162	28.4	109	7.8	302	6.4		237	4.3	115	17.7	320	7.7

[a] g/100 g dm.
[b] Acid detergent fiber.
[c] Coefficient of variation (%).
[d] Not available.

ratios can vary among hybrids and can affect fermentation efficiency; ethanol production was decreased as proportion of amylose increased (Sharma et al., 2007). Singh and Graeber (2005) found that ethanol yields varied 23% among maize hybrids, presumably due to differences in starch composition. Grinding (particle size reduction) is the first major step in the dry grind process. Particle size distribution of ground maize can affect starch hydrolysis and fermentation. A variety of factors impact particle size distribution, including moisture content of maize, sharpness of knives, size and integrity of screen openings, presence of foreign matter, *etc.* The distribution of ground maize was measured by Rausch et al. (2005); most of the material was retained on the two largest screen sizes (2.84 and 0.84 mm openings), but there was considerable variation among samples. Particle size distributions also can differ from plant to plant as well as from batch to batch within a plant (Liu, 2008; Rausch et al., 2005).

Finally, processing conditions can vary among fermentation batches. For example, in the fermentation step, there can be differences in solids concentration, temperature, types and amounts of additives, composition and amount of backset, water quality, *etc.* (Rausch and Belyea, 2006). After fermentation is completed, there are several steps which could be sources of variation. Whole stillage (material remaining after ethanol is stripped off) is centrifuged; separation is imperfect, and the resulting streams (wet grains and thin stillage) can vary in proportion and composition. Thin stillage is partially dewatered to form distillers solubles, which can vary considerably (Belyea et al., 1998). Wet grains and distillers solubles are combined to form wet distillers grains with solubles and dried to form DDGS. This (blending) step is difficult to control, and the proportions of the two streams can vary. Drying is the last processing step; conditions in the dryer can vary markedly and impact protein quality (Swietkiewicz and Koreleski, 2008; Young, 2008). The preceding sources of variation are presented as single factors, but there could be interactions. For example, particle size of ground maize could affect starch availability and fermentation; it also could affect the subsequent separation of whole stillage. Interactive effects make difficult the identification and control of variation in processing streams and, ultimately, composition of DDGS.

Table 5
Compositional[a] data of distillers dried grains with solubles from dry grind and wet mill processing.

Parameter	Dry grind processing				Wet milling	
	This study	Akayezu et al. (1998)	Shurson et al. (2001)	Arosemena et al. (1995)	NRC (1982)	Belyea et al. (1989)
NDF[b]	589	488	445	392	440	330
ADF[c]	237	155	162	197	180	150
Protein	320	301	302	247	250	306
RUP[d]	449	534	na[e]	na[e]	na[e]	na[e]
Fat	115	105	109	104	103	74
Ash	39	43	58	44	48	35
Ca	na[e]	na[e]	0.6	4.9	1.5	0.1
P	na[e]	na[e]	8.9	9.0	7.1	6.9
Mg	na[e]	na[e]	3.3	2.6	1.8	2.5
K	na[e]	na[e]	9.4	11.2	4.4	9.4
Na	na[e]	na[e]	2.4	3.7	5.7	1.5
S	na[e]	na[5e]	5.1	na[e]	3.3	na[e]
N	106	8	118	3	na[e]	na[e]

[a] g/kg DM for all measures, except RUP (g/kg total protein).
[b] Neutral detergent fiber.
[c] Acid detergent fiber.
[d] Ruminally undegradable protein.
[e] Not available.

DDGS compositional data published before about 1995 probably represented samples taken from the wet milling process, because the dry grind processing industry was being developed and produced limited quantities of coproduct. At the present time, wet milling and dry grind processing market similar quantities of material. Nutrient data for DDGS are used extensively in feed ingredient tables, such as NRC (1982), and in computer diet formulation programs. Because wet milling and dry grind processing use different technologies, composition of the resulting coproducts could vary. There are limited data to compare the composition of DDGS from the two sources. Data of four papers from dry grind processing and two from wet milling are summarized in Table 5. There were some apparent differences in composition associated with the two processes. In general, DDGS from dry grind processing had higher concentrations of fiber, protein and fat, although there was considerable variability. The concentrations of elements in DDGS from dry grind processing were similar to each other and to a recent publication from our lab (Belyea et al., 2006). In general, element concentrations were higher for DDGS from dry grind processing than from wet milling. This could be due to chemicals added during dry grind processing to maintain optimal fermentation conditions. One source (Arosemena et al., 1995) reported high calcium concentrations; the reason for this is not known. Overall, these data indicated that the nutrient concentrations of DDGS from dry grind processing could be different from those for DDGS from wet milling. This underscores the importance of having relevant compositional data when formulating diets containing DDGS.

High RUP content of DDGS is important to animal producers, because of potential to improve protein utilization and animal productivity. It is important to ethanol plant personnel because it affects market value. Precise estimates of RUP could improve diet formulation, but variation makes this difficult. Because variation is associated with fermentation batches, estimating the RUP content of each batch of DDGS probably would be the most accurate approach. However, it would be virtually impossible for ethanol plant personnel to do this, because of time constraints, analytical limitations and other reasons. As a result, published values for RUP concentrations typically are assumed. A possible alternative would be for personnel to develop prediction equations based on data from DDGS samples specifically from their processing plant. In the present study, equations were developed for each plant; these equations (data not shown) were quite diverse. To simplify comparisons, RUP concentrations were estimated using the two most divergent plant-specific equations; estimates also were obtained using the overall equation. Mean RUP concentrations were 433, 440 and 446 g RUP/kg total protein, respectively, for the two plant-equations and the overall equation. These estimates were similar to each other and to published data (470 g/kg total protein, NRC, 2001). This suggests that published values for RUP content of DDGS processing were as valid as estimates from plant-specific equations or from the overall equation.

High RUP content is an important characteristic of DDGS, because of the potential to increase the quantity of essential amino acids (EAA) in the metabolizable amino acid pool. There are few published data that document the EAA concentrations of RUP from DDGS; it generally is assumed that they are similar to concentrations in the total protein fraction. The profile of EAA in DDGS generally reflects that of maize; values will increase about threefold, due to the concentrating effect of starch disappearance during fermentation. Concentrations of most EAA in maize in the present study (Table 6) were similar to values published in NRC (1982). Concentrations of EAA in DDGS from the present study are compared in Table 6 to data from others (Shurson et al., 2001; NRC, 1982). Amino acid concentrations of DDGS in our study generally were somewhat higher than those reported by Shurson et al. (2001); however, the differences were not large (about 10% or less) and could be due to differences in sampling. Most amino acid concentrations for DDGS from NRC (1982) were similar to the other two sources of data.

The optimal profile of EAA in the metabolizable amino acid pool for ruminants is controversial; ruminal microbial protein (NRC, 2001) often is used as a reference point. The profiles of EAA in DDGS from the present study are compared to those of

Table 6
Essential amino acid concentrations of maize and distillers dried grains with soluble (DDGS) samples (g/kg DM).

Amino acid	Maize		DDGS		
	This study	NRC[a]	This study	NRC[a]	Shurson et al.[b]
Arginine	4.3	5.4	13.4	10.5	12.0
Histidine	2.7	2.5	7.9	7.0	7.6
Isoleucine	2.9	3.9	11.2	15.2	10.0
Leucine	10.9	11.2	34.3	24.3	29.7
Lysine	3.0	2.4	8.9	7.7	5.3
Methionine	1.7	2.1	5.3	5.4	5.0
Phenylalanine	4.4	4.9	14.9	16.4	12.7
Serine	4.3	5.3	13.4	14.2	–
Threonine	3.4	3.9	11.4	10.1	9.8
Tyrosine	2.9	4.3	11.1	7.6	–
Valine	4.4	5.1	15.1	16.3	15.0

[a] NRC (1982).
[b] Shurson et al. (2001).

microbial EAA (NRC, 2001) in Fig. 4. The concentrations of most EAA in DDGS were similar to corresponding concentrations in microbial protein. However, two amino acids varied quite considerably. Leucine concentration was much greater than that of microbial protein; the effects of this are unclear. Lysine concentration was less than half that of microbial protein. This could have adverse effects on productivity, depending on the concentration of lysine in other ingredients. Pepsin insoluble protein concentrations averaged 228 g/kg total protein (Table 2) and ranged from 150 to 400 g/kg total protein (Fig. 3). The concentration in feed material not exposed to high temperature is about 150 g/kg total protein. Thus, the pepsin insoluble protein content of DDGS (and, presumably RUP) was elevated, indicating that availability of some amino acids could be reduced. Because lysine is vulnerable to heat damage, it could be affected more than other amino acids. There are few published data on lysine availability of DDGS when fed to ruminants. For non-ruminants, the data are conflicting. In broilers, Swietkiewicz and Koreleski, 2008 and Youssef et al. (2008) found that the protein of DDGS was highly digestible and that lysine availability was greater than 75%. Young (2008) and Shurson et al. (2001) reported that that lysine availability varied from about 44 to about 78% when fed to growing swine. In these (non-ruminant) studies, there were no lab measures of protein availability, and there was little information describing processing conditions. This makes it difficult to explain differences in protein and/or lysine availability among studies.

5. Conclusions

The composition of DDGS was variable and was associated with variation among fermentation batches; differences in maize characteristics and/or processing conditions were responsible for batch to batch effects. Variation in protein and low lysine concentrations content were concerns. Published values for ruminally undegradable protein content of DDGS were as accurate as estimates derived data from specific plant data. Pepsin insoluble (bound) protein was elevated, and the availability of essential amino acids, especially lysine, could be adversely affected.

Acknowledgements

The authors recognize the technical assistance of Andrea Lloyd, Lindsey Parsons, Brandi Reeves and Donna Dolan in carrying out this project. They also appreciate financial support from the Illinois Council for Food and Agricultural Research (CFAR) under Award No. 02E-070-1.

References

Akayezu, J.M., Linn, J.G., Harty, S.R., Cassady, J.M., 1998. Use of distillers grains and co-products examined. Feedstuffs 70, 11–13.
AOAC, 1997. Official Methods of Analysis of AOAC International, 16th ed. AOAC Intern., Gaithersburg, MD.
Arosemena, A., DePeters, E.J., Fadel, J.G., 1995. Extent of variability in nutrient composition within selected by-product feedstuffs. Anim. Feed Sci. Technol. 5, 103–120.
Belyea, R.L., Steevens, B.J., Restrepo, R.J., Clubb, A.P., 1989. Variation in composition of by-product feeds. J. Dairy Sci. 72, 2339–2345.
Belyea, R.L., Rausch, K.D., Tumbleson, M.E., 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Bioresour. Technol. 94, 293–298.
Belyea, R., Eckhoff, S., Wallig, M., Tumbleson, M., 1998. Variability in the nutritional quality of distillers solubles. Bioresour. Technol. 66, 207–212.
Belyea, R.L., Clevenger, T.E., Singh, V., Tumbleson, M.E., Rausch, K.D., 2006. Element concentrations of dry grind corn processing streams. Appl. Biochem. Biotechnol. 13, 113–128.
Goering, H.K., Gordon, C.H., Waldo, D.R., Van Soest, P.J., Smith, L.W., 1972. Analytical estimates of nitrogen digestibility in heat damaged forages. J. Dairy Sci. 55, 1275–1280.
Krisnamoorthy, U., Sniffen, C.J., Van Soest, P.J., 1982. Nitrogen fractionation in ruminant feedstuffs for feed evaluation. In: Cornell Nutr. Conf. Feed Manf., Syracuse, NY.
Liu, K., 2008. Particle size distribution of distillers dried grains with solubles (DDGS) and relationships to compositional and color properties. Bioresour. Technol. 99, 8421–8428.
NRC, 1982. United States-Canadian Tables of Feed Composition, 3rd ed. Nat. Acad. Press, Washington, DC.

NRC, 2001. Nutrient Requirements of Dairy Cattle, 7th ed. Nat. Acad. Press, Washington, DC.
Rausch, K.D., Belyea, R.L., 2006. The future of coproducts from corn processing. Appl. Biochem. Biotechnol. 12, 47–86.
Rausch, K.D., Belyea, R.L., Ellersieck, M.R., Singh, V., Johnston, D.B., Tumbleson, M.E., 2005. Particle size distributions of ground corn and DDGS from dry grind processing. Am. Soc. Agric. Eng. 48, 273–277.
SAS, 2003. Statistical Analysis Guide: Statistics, Ver. 9. SAS Institute, Cary, NC.
Sharma, V., Rausch, K.D., Tumbleson, M.E., Singh, V., 2007. Comparison between granular starch hydrolyzing enzyme and conventional enzymes for ethanol production from maize starch with different amylase:amylopectin ratios. Starch/Starke 59, 549–556.
Shurson, J., Spiehs, M., Whitney, M., Baidoo, S., Johnston, L., Shanks, B., Wulf, D., 2001. The value of distillers dried grains with solubles in swine diets. In: Mn. Nutr. Conf. Mn. Corn Growers Assoc. Tech. Sympos., Bloomington, MN.
Singh, V., Graeber, J.V., 2005. Effect of corn hybrid variability and planting location on dry grind ethanol production. Am. Soc. Agric. Eng. 48, 709–714.
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber and non starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 73, 3583–3597.
Stern, M.D., Satter, L.D., 1984. Evaluation of nitrogen solubility and the dacron bag technique as methods for estimating protein degradation in the rumen. J. Anim. Sci. 58, 714–724.
Swietkiewicz, S., Koreleski, J., 2008. The use of distillers dried grains with solubles (DDGS) in poultry nutrition. World's Poultry Sci. Assoc. 64, 257–265.
Young, M., 2008. Using dried distillers grains with solubles (DDGS) in swine diets. In: 8th London Swine Conf., London, Ontario, Canada.
Youssef, A.M.I., Westfahl, C., Sunder, A., Leibert, F., Kamphues, J., 2008. Evaluation of dried distillers' grains with solubles (DDGS) as a protein source for broilers. Arch. Anim. Nutr. 62, 404–414.