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Composition of corn and distillers dried grains with solubles from dry grind ethanol processing

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Abstract

Increase in the demand for ethanol has resulted in growth in the dry grind (DG) ethanol industry. In DG processing, the whole corn kernel is fermented, resulting in two main coproducts, ethanol and distillers dried grains with solubles (DDGS). Marketing of DDGS is critical to the economic stability of DG plants. The composition of DDGS can vary considerably; this reduces market value. Factors that cause variation in composition need to be evaluated. The objective was to determine the relationship between composition of corn and composition of DDGS. Samples of corn and DDGS were obtained from a DG ethanol plant and analyzed for protein, fat, starch and other nutrients. Concentrations of protein, fiber and starch were similar to published data for corn but were higher for DDGS. Coefficients of variation for protein fat and fiber concentrations were similar for corn and DDGS. There were no significant correlations between concentrations of components in corn and those in DDGS. Variation in the composition of DDGS was not related to variation in corn composition and probably was due to variation in processing streams or processing techniques. This implies that reducing the variation in composition of DDG will require modification of processing strategies.

Keywords: Corn; DDGS; Nutrient concentrations; Variation

1. Introduction

Increase in the demand for ethanol as a fuel additive has resulted in a dramatic increase in the amount of corn used for ethanol production (Shapouri et al., 2002). Corn can be converted into ethanol by either wet milling or dry grind (DG) processing (Singh et al., 2001). Wet milling requires extensive equipment and high capital investment; large volumes of ethanol are produced, and there are a variety of coproducts to defray production costs. On the other hand, DG plants are smaller than wet mill plants, require less equipment and have lower capital investment. They generally are owned by producers and contribute significantly to local economies (Singh et al., 2001). DG plants produce only two major coproducts: ethanol and distillers dried grains with solubles (DDGS); marketing of DDGS is critical to sustainability of DG plants. Factors that affect quality of DDGS directly impact the economics of ethanol production (Singh et al., 2001). One factor that affects market value is variation. The composition of DDGS can vary substantially (Belyea et al., 1989); this reduces quality of DDGS and negatively impacts market value.

Protein is the most expensive nutrient in animal diets; variation in the proportion of protein in feeds can cause misformulation and can affect animal productivity. The protein content of DDGS can range from 27% to 35% (Belyea et al., 1989). If a producer were to formulate diets based on expected average protein concentration (31%) of DDGS, the resulting diets could either have insufficient protein, which probably will reduce animal productivity, or excessive protein, which is unnecessary, expensive and not environmentally sound. The source of variation in composition of DDGS is not well documented. We have shown that distillers solubles, one of the major parent streams for DDGS, has considerable variation in composition (Belyea et al., 1998). However, there probably are other sources of variation. An

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assumption commonly expressed by corn processors is that variation in the composition of corn is a major cause of variation in composition of the DDGS. There are few, if any, published data to examine this relationship. The objective was to determine relationships between composition of corn and composition of DDGS.

2. Methods

The experiment was conducted with cooperation from a DG ethanol plant located in Minnesota. Corn processed by this plant was purchased from local producers located within about 60 km of the plant. The soil type in this region was silty loam. Temperature data were obtained from the National Climate Data Center (NCDC, 2002); precipitation data were obtained from University of Minnesota archives (UMN, 2002). Temperature and precipitation data were used to document general growing conditions for corn for five years (1997–2001) during which the study was conducted. Samples of corn were obtained one day per month during 1997, 1998, 1999 and 2000 and during the first nine months of 2001. Samples were obtained from storage bins as corn was being ground prior to fermentation. On a given sample day, aliquots of corn were taken approximately every 2 h over a 24 h period and composited. Samples of DDGS were taken one day per week during each month of the study; on a given sample day, aliquots were taken from a sampling port every 2 h over a 24 h period. These were combined to form a daily sample.

There is a considerable lag between initial processing steps (grinding of corn) and the production of DDGS at the end of fermentation; matching corn samples and DDGS samples (i.e., from the same fermentation batch) is very difficult to achieve accurately and was not attempted. However, if there were disruptions in fermentation or other processing steps during an expected DDGS sampling period, sampling was delayed until processing conditions were normal and in a steady state. To the extent possible, both corn and DDGS samples were taken when processing conditions were as stable as possible.

Part of each corn sample was analyzed for bulk density by determining weight (kg) contained in a 1.0 l container according to standard procedures (USDA, 1997). The remaining portion of the samples of corn and the DDGS samples were sent to a commercial analytical lab for analyses. Samples of corn were analyzed for dry matter (DM), protein, fat, crude fiber and starch using standard methodologies (AOAC, 1984). Samples of DDGS were analyzed for dry matter, fiber, fat, starch, lignocellulose and ash using standard methods (AOAC, 1984).

Data were analyzed for effects of year using a simple block design (SAS, 1985); means (as least squares means) were compared for effects of year when main effects were significant. Pearson correlation coefficients were calculated using SAS (1985) procedures to determine relationships between components of corn and components of DDGS.

3. Results and discussion

Corn grows optimally when mean daytime temperatures are at least 21–27 °C and when mean nighttime temperatures are 13 °C or greater (Martin et al., 1976). Growth can be suppressed when temperatures are below optimum (Martin et al., 1976). Temperature data for spring and summer months during the five years of the study are summarized in Table 1. Across years, mean maximum daytime temperatures during the growing months (May–September) ranged from 21.7 °C in May to 28.7 °C in July. Within years, maximum daytime temperatures were at least 21 °C in nearly all growing months. Mean nighttime temperatures were below 13 °C in May and September but were above 13 °C during June, July and August. The mean maximum daytime and mean minimum nighttime temperatures during the five years of this study were very similar to published 30 year averages for the area (Table 1).

Corn typically requires a minimum of 38 cm of annual precipitation for optimal growth, although 61–102 cm are preferred (Martin et al., 1976). During the growing months (June, July and August), a minimum of 20 cm of precipitation is required for corn to grow normally (Martin et al., 1976). Precipitation (Table 2) was highly variable from month to month within years as well as across years. However, precipitation amounts during the growing months exceeded 20 cm during all five years and were similar to 30 year averages (Table 2).

These temperature and precipitation data substantiated that the average climatic conditions (temperature and moisture) during the five years in which the corn in this study was grown were similar to those for long term (30 year) average conditions. Temperatures and precipitation levels were adequate to meet growing requirements of corn. These data can be interpreted to mean that corn being processed during this study appeared to be generally representative of corn grown in the area of the ethanol plant. There did not appear to be significant deviations in climatic conditions that might result in abnormal corn growth or composition.

Composition of corn is presented in Table 3. There were some significant effects of year on composition of corn. For example, bushel weight was lower in 1997 than other years. Fat content of corn samples was higher in 1997, 1999 and 2000 than in 1998 and 2001. Protein content was highest in 1997 and 2000 and lowest in 1998. Starch content also was affected by year; it was lowest in 1998. It should be noted that in cases in which means were significantly different, the differences were

Table 1
Temperature (°C) data for corn growing seasons

Month	Year					Av[a]	Av[b]
	1997	1998	1999	2000	2001		
April							
Max[c]	11.8	17.3	14.9	14.4	13.2	14.2	13.7
Min[d]	−0.4	3.1	3.2	0.9	1.8	1.7	1.3
May							
Max	19.0	24.7	20.8	22.2	21.2	21.7	21.4
Min	5.4	10.7	9.8	9.6	10.0	9.0	8.0
June							
Max	30.9	24.1	25.7	24.8	26.6	26.4	26.4
Min	15.0	12.9	14.8	13.3	14.3	14.1	13.4
July							
Max	26.5	30.6	29.6	27.7	29.3	28.7	29.1
Min	16.4	17.0	17.9	16.4	17.6	17.1	16.1
August							
Max	25.7	27.8	26.9	27.8	28.7	27.4	27.6
Min	14.8	16.5	15.5	15.9	15.6	15.7	14.6
September							
Max	24.0	25.9	18.3	23.1	21.4	22.6	22.1
Min	11.6	11.9	8.8	8.6	10.1	10.2	9.1

[a] Averages for 1997–2001.
[b] Thirty year average (NCDC, 2002).
[c] Mean maximum temperature for month.
[d] Mean minimum temperature for month.

Table 2
Precipitation (cm) during corn growing seasons

Month	Year					Av[a]	Av[b]
	1997	1998	1999	2000	2001		
April	4.85	4.27	4.88	2.77	17.93	6.93	6.07
May	3.73	8.56	11.91	9.09	6.53	7.98	7.67
June	6.65	10.41	9.80	6.58	11.58	8.99	11.15
July	14.24	9.55	13.21	13.92	7.90	11.76	8.92
August	9.32	12.09	11.02	4.16	3.12	7.92	8.71
September	5.94	2.21	5.76	2.44	7.82	4.83	7.16

[a] Averages for 1997–2001.
[b] Thirty year average (NCDC, 2002).

small from a biological standpoint. For example, the starch concentration of corn in 1998 was significantly lower than in other years, but the difference was very small (≈1% unit). It is unlikely that this would have much impact on processing efficiency or composition of DDGS. A similar case could be made for fat and protein. Mean concentrations for fat, protein and starch for corn in the present data were very similar to other published data (NRC, 1982; Watson, 1987).

Composition of DDGS is presented in Table 4. All parameters were significantly affected by year. Fat content of DDGS increased from 1997 to 1999 and remained uniform thereafter. Protein content also increased with time; it was lowest in 1997 and increased in 1998 and 1999. Crude fiber was lower in 2000 than the other years, which were not different, while ADF was higher in 1999 than the other years. Ash content of DDGS was higher in 1998 than the other years. Starch content increased with each year; it was lowest in 1997 and highest in 2001. The mean concentrations of nutrients in DDGS in the present study differed somewhat from published data (MNC, 2001; NRC, 1982). However, because the latter data probably were obtained from a different industry (wet milling or beverage ethanol processing), this is not surprising.

While many of the changes in nutrient concentrations across years were significant, differences were small from a biological point of view and difficult to explain. The first year of the study (1997) was the first operational year for the ethanol plant. Processing equipment and strategies were not operating at optimum levels initially. Increase in fat, protein and ADF content of DDGS with

Table 3
Composition of corn samples

Year	*N*	BD[1] (kg/l)	Crude (g/100 g dry matter)		
			Fat	Protein	Starch
1997	12	0.69[a]	4.25[c]	9.17[a]	71.6[a]
1998	12	0.73[b]	4.12[b]	8.94[b]	70.6[b]
1999	10	0.74[b]	4.36[d]	9.02[ab]	71.5[a]
2000	11	0.73[b]	4.27[c]	9.23[a]	71.7[a]
2001	9	0.73[b]	4.04[a]	9.11[a]	71.8[a]
Mean		0.72	4.21	9.10	71.4
SE[2]		0.004	0.06	0.09	0.32
NRC[3]		nd[4]	4.30	9.50	71.7

[abcd]Means within a column with unlike letters differ ($P < 0.05$).
[1] Bulk density.
[2] SE = standard error.
[3] NRC (1982).
[4] Not determined.

Table 4
Composition of DDGS (g/100 g dry matter)

Year	*N*	Crude fat	Protein	Crude fiber	ADF	Ash	Starch
1997	48	10.9[a]	28.3[a]	10.4[a]	15.4[a]	4.3[a]	4.7[a]
1998	52	11.9[b]	30.8[b]	10.6[a]	16.3[a]	5.0[b]	4.9[ab]
1999	51	12.3[c]	31.5[c]	10.3[a]	19.3[b]	4.5[a]	5.2[b]
2000	48	12.4[c]	32.9[d]	9.6[b]	15.7[a]	4.5[a]	5.7[c]
2001	36	12.6[c]	33.3[e]	10.1[a]	17.1[a]	4.5[a]	5.9[c]
Mean		11.9	31.3	10.2	17.2	4.6[a]	5.1[b]
SE[1]		0.11	0.21	1.2	1.2	0.20	0.26
MNC[2]		10.9	30.2	8.8	nd[3]	5.8	nd
NRC[4]		11.8	29.2	9.8	nd	5.8	nd

[abcde]Means within a column and with unlike letters differ ($P < 0.05$).
[1] SE = standard error.
[2] MNC (2001).
[3] Not determined.
[4] NRC (1982).

time would suggest that processing efficiency might have increased (more complete fermentation, concentrating fat and protein). However, ash content was unchanged and starch content actually increased; these changes do not support to the concept of increased processing efficiency.

Variation in nutrient concentrations can be expressed in different ways. Actual variation (highest minus lowest value) is a simple and common means of expressing variation. However, if two parameters are markedly different in magnitude, actual variation can be misleading. Another measure of variation is the coefficient of variation (CV), which reflects magnitudes, as well as distribution. Depending upon which measure of variation are used, different interpretations can be obtained. This is illustrated in Table 5. Actual variation in fat content of corn was 0.32% units, compared to 1.60% units for fat content of DDGS. On this basis, actual variation for DDGS was about five times greater than for corn. However, CVs were quite similar (6.54% and 4.71%, respectively). Likewise, actual variation in protein content of corn and DDGS was 0.29% and 5.0% units, whereas CVs were 3.62% and 4.69%, respectively. Thus, the argument that the variation in protein (or fat) content of DDGS is greater than in corn depends on how variation was expressed.

Table 5
Variation in fat and protein concentrations of corn and DDGS

Item	Corn	DDGS
Fat		
Actual variation (% units)	0.32	1.60
COV (%)	4.71	6.54
Protein		
Actual variation (% units)	0.29	5.00
COV (%)	3.62	4.69

There were no significant correlations between components of corn and components of DDGS (Table 6). Many corn processors attribute the variation in protein content of DDGS to variation in the protein in corn. The data of this study indicate that there was no basis

Table 6
Correlations between corn and DDGS components

Corn	DDGS				
	Fat	Protein	Starch	ADF	Crude fiber
Fat	−0.15	−0.06	0.11	0.16	0.03
Protein		0.04	0.15	0.02	0.12
Starch			−0.21	0.01	−0.03

for this assumption. Considering the transformations in corn components during processing and fermentation, lack of correlation among corn and DDGS components was not surprising. However, there were significant correlations among components within DDGS (Table 7). Fat and starch were significantly correlated with protein (0.82 and 0.37, respectively); the correlations between ADF and fat (0.63), ADF and protein (0.59) and starch (0.28) were significant. Crude fiber was negatively correlated with other components. These data suggested that some components of DDGS are correlated with each other, probably reflecting the concentrating effect of starch disappearance during fermentation.

Variation in protein content of DDGS could have been due to several factors. DDGS are formed when two processing streams, wet grains (WG) and distillers solubles (DS), are combined (Singh et al., 2001). It has been shown that composition of DS can vary significantly from batch to batch (Belyea et al., 1998). It is likely that the protein content of WG varied from batch to batch, although there were no corroborative published data. The process of blending of WG and DS prior to drying was not well controlled; therefore, variation in proportion of WG to DS also could have contributed to variation in protein (and other nutrients) in DDGS. The protein in DDGS was derived from two main sources—yeast and corn. As yeasts grew, they fermented starch and produced cell mass, much of which was yeast protein (≈60 g/g 100 dm, NRC, 1982). Therefore, a proportion of the protein in DDGS was of yeast origin. In addition, corn contains moderate amounts of protein (≈9 g/100 g dm). Yeasts lack proteolytic enzymes and cannot degrade corn protein (Rose and Harrison, 1987); non-protein nitrogen compounds (urea or ammonia) are used as N sources. The extent to which corn protein was degraded during fermentation was not well documented but was presumed to be minimal. Therefore, a significant portion of the protein in DDGS could have been corn protein. The proportion of yeast protein to corn protein in DDGS is not well documented in the literature. Data on essential amino acid concentrations of yeasts, corn and DDGS are in Table 8. Yeast protein contains higher concentrations of most amino acids than corn or DDGS. The ratio of DDGS amino acid concentrations to yeast amino acid concentrations (Table 8) varied considerably among amino acids. However, most ratios were from 0.45 to 0.70, and the average ratio was 0.55, suggesting that yeast protein may make up approximately half of the protein in DDGS. For certain amino acids, such as lysine, the high concentrations in yeast protein (3.32 g/10 g) balance the typically low concentration in corn (0.24 g/100 g) and resulted in relatively high concentrations in the DDGS (0.77 g/100 g).

Variation in fat and protein content affects market value of DDGS. Protein content of the DDGS in this study varied from 28.3% to 33.3%. Corn processors typically market DDGS with a conservative estimate of nutrient content to ensure that label specifications are met. This often results in underestimation of protein concentrations of diets. For example, if a diet were formulated on the assumption that DDGS contained 33% protein, when, in fact, it actually contained 28% protein, the animals consuming that diet most likely would be protein deficient. That could substantially reduce animal production. Therefore, producers usually formulate diets using conservative nutrient concentrations. If a diet were formulated assuming that DDGS contained 28% protein and it actually contained 33%

Table 7
Correlations among components in DDGS

Component	Fat	Protein	Starch	ADF	Crude fiber
Fat		0.82**	0.20	0.63**	−0.23*
Protein			0.37**	0.59**	−0.24*
Starch				0.28*	−0.37*
ADF					−0.12
Crude fiber					

* $P < 0.10$.
** $P < 0.01$.

Table 8
Essential amino acid content (g/100 g dry matter) of yeast, corn and DDGS[a] protein[b]

Amino acid	Yeast	Corn	DDGS	YC[c]
Arginine	2.35	0.54	1.05	0.45
Histidine	1.17	0.25	0.70	0.59
Isoleucine	2.37	0.39	1.52	0.64
Leucine	3.45	1.12	2.43	0.70
Lysine	3.32	0.24	0.77	0.23
Methionine	0.79	0.21	0.54	0.68
Phenylalanine	1.96	0.49	1.64	0.84
Threonine	2.27	0.39	1.01	0.45
Tryptophan	0.55	0.09	0.19	0.35
Tyrosine	1.60	0.43	0.76	0.48
Valine	2.52	0.51	1.63	0.64

[a] DDGS = distillers dried grains with solubles.
[b] From NRC (1982).
[c] YC = ratio of DDGS amino acid concentration: yeast amino acid concentration.

protein, then protein would be underutilized and could result in unnecessary N excretion. Marketing DDGS by assuming conservative nutrient concentrations short-changes the true potential of DDGS. While much attention is given to protein in DDGS, fat also is an important nutrient, because it increases available energy concentrations. Both fat and protein affect market value of DDGS. DDGS with high fat (12.6%) and high protein (33.3%) is worth about \$5–\$20 per ton more from a nutrient content basis than DDGS with lower fat (10.9%) and lower protein (28.0%). Thus, identifying sources of variation in nutrient concentrations and finding ways to reduce variation is important to maintaining sustainability of dry grind processing.

4. Conclusions

The composition of corn in the present study was very similar to published (NRC, 1982) values. However, DDGS contained higher fat, protein and fiber than NRC (1982), presumably, due to differences in processing technologies. Coefficients of variation for composition of DDGS were similar those for corn. There were no significant correlations among nutrients in corn and nutrients in DDGS. The assumption that variation in composition of DDGS was due to variation in composition of corn was not supported by the data of this study. Other possibilities, such as variation in composition of or the proportion of process streams used to produce DDGS, need to be examined.

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