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Element Concentrations of Dry-Grind Corn-Processing Streams

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Abstract

The dry-grind corn process is one of two technologies used to convert corn into ethanol. In this process, all kernel components are processed through several sequential steps, including fermentation. Only one coproduct (distillers' dried grains with solubles [DDGS]) is available for marketing. DDGS provide income to offset costs of processing; issues that affect marketing have implications in the economic viability of dry-grind plants. Two issues relate to elements in DDGS: high concentrations and excessive variation. Data on element concentrations in dry-grind processing streams could be helpful in addressing these concerns. The objective of this study was to determine element concentrations in primary process streams from dry-grind plants. Samples of corn, ground corn, beer, wet grains, syrup, and DDGS were obtained from nine dry-grind plants, and element concentrations were determined. The concentrations of most elements in corn were not different among processing plants and were similar to published data. However, for the processing streams, there were differences in several element concentrations among processing plants. The concentrations of most elements in beer were about three times those of corn, due to the disappearance of starch during fermentation. Syrup had the highest element concentrations. Variations in element contents of DDGS and parent streams were due to processing conditions and not corn. Appropriate processing of thin stillage (the parent stream of syrup) could reduce the element content of DDGS.

Index Entries: Distillers' dried grains with solubles; ethanol; dry-grind processing; stillage; syrup; element concentrations.

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Introduction

Because of increased demand for the use of ethanol as a fuel additive, ethanol production has increased markedly in the past decade. Ethanol is produced from corn by either wet-milling or dry-grind processing. In wet milling, several coproducts are produced for marketing. In dry grind there is only one coproduct, distillers' dried grains with solubles (DDGS). Most of the recent increase in ethanol production capacity has been from growth in the dry-grind industry; this has resulted in an increase in the amount of DDGS. Marketing of DDGS is important to the economic sustainability of dry-grind processing plants, because the income offsets much of the cost of ethanol production. Therefore, factors that affect DDGS marketing can affect the economic status of dry-grind plants.

Two issues related to element content that impact the marketing of DDGS are high concentrations and variability. Elevated element concentrations can impact practical utilization. Of greatest concern are high concentrations of phosphorus (P) and sulfur (S). High dietary P concentrations can lead to excess P consumption and high P concentrations in wastes. High P concentrations in animal wastes can result in waste disposal difficulties. To control P in wastes, some animal producers may have to limit the amounts of DDGS used in diets. Excessive dietary S concentrations can result in high hydrogen sulfide concentrations in the rumen of ruminants. This can cause a functional thiamine deficiency and deterioration of the brain. High S content may affect the market potential of DDGS.

Element concentrations of DDGS are variable *(1–3).* This makes accurate diet formulation difficult, because assumed concentrations could be different from actual concentrations. To prevent the potential for underfeeding, producers often formulate diets on the assumption that element concentrations are low. This practice results in overfeeding of nutrients, which can result in excess elements in wastes and can lead to nutritional disorders.

Nutritional and market values of DDGS could be sustained, if not improved, if certain element concentrations could be reduced and if variation could be minimized. This will require modification of key processing steps. Before strategies can be devised to modify processing, it is necessary to acquire data that characterize processing stream element concentrations. There are few, if any, published data that document element concentrations of processing streams. The objectives of the present study were to determine element concentrations in key dry-grind processing streams and to identify which streams present the greatest opportunity for modification.

Materials and Methods

Nine dry-grind processing plants located in the upper midwest (Minnesota, Missouri, South Dakota) were sources of samples for characterization. Plant production capacities ranged from 20 to 40 million gal of

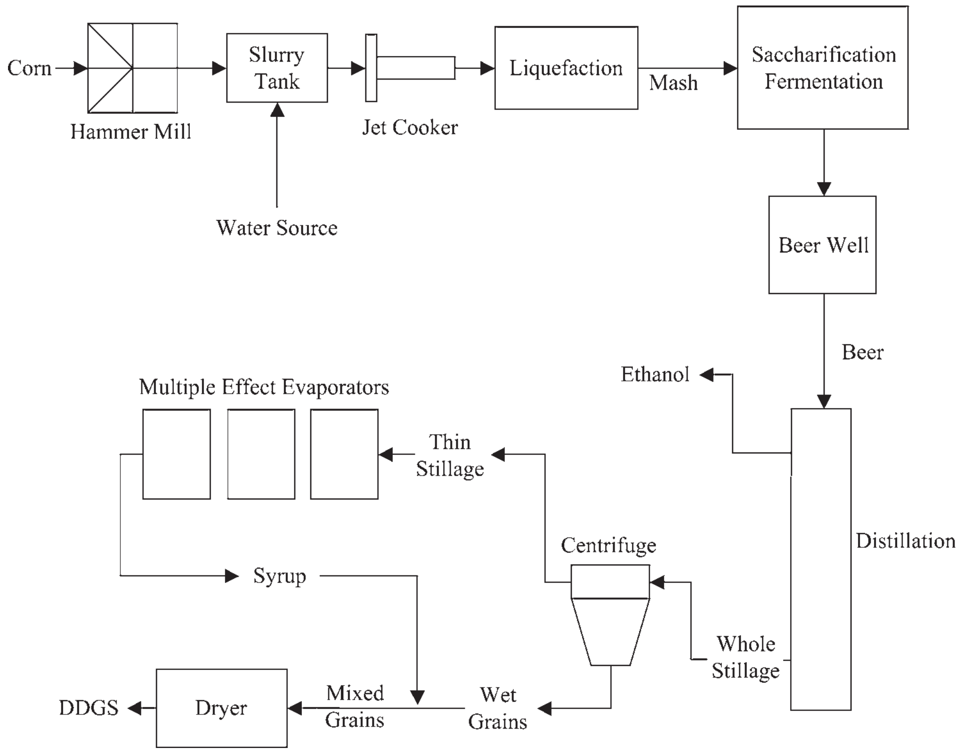

Fig. 1. Process streams in a dry-grind plant.

ethanol/yr; processing equipment and strategies were similar among plants. Corn used by each plant was obtained from corn producers in the immediate geographic area. Dry-grind plants were located in several states; the corn used represented a wide variety of climatic and agronomic conditions and presumably included many different commercial corn hybrids.

Dry-grind fermentation (Fig. 1) is a batch process; consequently, fermentation and associated processing streams were distinct and isolated from other batches. The time needed to process a batch of corn into ethanol varied among plants and ranged from 60 to 90 h. Samples were taken from particular processing streams as a specific batch of corn was processed into ethanol. There were two sampling periods (fall and winter); within each period, samples were taken during three different intervals of 3 to 4 d (referred to as collection weeks). During a collection week, samples (about 500 g) were taken from the following process streams: corn, ground corn, beer, mixed grains, syrup, and DDGS (Fig. 1). Samples of corn were obtained from the storage bin just before it entered the hammer mill. Ground corn samples were obtained from the hammer mill as the 15-h grind progressed to provide sufficient corn for one fermentation batch. Samples of corn and ground corn were taken every 3 h, resulting in five samples of whole corn and five samples of ground corn. The beer sample was taken from the beer well after the fermentor was emptied into the beer well. Syrup samples were taken from the syrup line downstream from the evaporator just prior to blending with the wet grains. Samples of mixed grains were taken from the conveyor just prior to mixing with syrup. DDGS samples were taken from the transport conveyor prior to being added to existing DDGS in the storage facility. Each sample was frozen, because several of the streams had high water content. After a set of samples was complete, it was shipped to the University of Missouri for processing and analyses.

The five samples of corn and ground corn were each combined and subsampled to form composites of about 500 g; samples of beer and wet grains were dried at 55°C and syrup samples were lyophilized. Samples of corn, ground corn, and DDGS did not require drying. All samples were ground to pass through a screen having 2.0-mm openings. Analytical dry matter was determined as weight loss when dried at 105°C for 12 h *(4)*. Sample ash contents were determined using a microwave digestion system. Element concentrations were determined using inductively coupled plasma (ICP) methodology *(2)*. Data were analyzed statistically for effects of period, week, and period x week interaction using a general linear model *(5)*. When main effects were significant ($p < 0.01$), means were separated using the least squares means procedure.

Results and Discussion

Composition of Dry-Grind Process Streams

Corn and Ground Corn

Mean concentrations of most elements were not different among ethanol plants ($p < 0.01$; Table 1). Fe concentration (177 mg/kg) for plant 1 was higher than for any other plant; the reason for this is not clear. This plant also had high Ni concentrations. For ground corn, mean concentrations of most elements also were not different among plants (Table 2). Element concentrations of ground corn were similar to those of corn, as would be expected. Concentrations of priority pollutants in corn and ground corn, such as As, Ag, Cd, and Pb, were either low or below detection limits (data not shown). This is consistent with the findings of our previous studies *(2,6)*, in which streams from a variety of food-processing plants had low or undetectable concentrations of priority pollutants.

Beer

Mean element concentrations of beer were much higher than for corn (Table 3). For example, mean concentrations of Ca, K, Mg, and P in corn were 51, 3590, 1130, and 2910 mg/kg, respectively, compared with 334, 14,200, 4350, and 10,200 mg/kg, respectively, in beer. The increase was assumed to be due to the concentrating effect of the disappearance of starch during fermentation. The mean concentration of Na in beer was 1202 mg/kg, compared with 5.4 mg/kg for corn; this was a greater increase than for other elements. High Na probably was due to the use of NaOH for sanitation of process lines and fermentors. Typically, cleaning materials are rinsed

Table 1
Element Content of Corn From Dry-Grind Plants[a]

	Plant									Least squares mean	SE
	1	2	3	4	5	6	7	8	9		
Ca	56	50	44	45	76	51	47	42	50	51	11.0
Cu	2.1	1.8	1.5	1.6	1.6	1.7	1.6	1.3	1.4	1.6	0.20
Fe	177*	21†	21†	23†	32†	23†	22†	22†	21†	35	28.0
K	3660	3550	3630	3610	3540	3500	3770	3420	3600	3590	136
Mg	1140	1180	1100	1130	1150	1100	1150	1140	1110	1130	60.5
Mn	7.4	5.1	4.8	5.6	5.8	6.0	5.6	5.0	5.1	5.5	0.76
Na	4.8	7.5	6.8	3.9	ND	ND	5.8	4.9	4.5	5.4	1.20
Ni	1.5*	0.9‡	1.2†	1.2†	0.6‡	0.6§	1.3*,†	0.9‡	1.0‡	1.0	0.20
P	2800	2960	3080	3190	2720	2680	3010	2700	3010	2910	150
S	1270	1100	1020	1810	1510	1490	1240	1190	1190	1320	296
Zn	20	18	20	21	20	18	20	18	18	19	1.10

[a]Values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$). ND, not determined.

Table 2
Element Content of Ground Corn From Dry-Grind Plants[a]

	Plant										
	1	2	3	4	5	6	7	8	9	Least squares mean	SE
B	2.9	3.7	3.1	ND	3.5	2.8	2.8	3.2	2.1	3.0	0.44
Ca	92	47	51	53	47	52	49	46	61	56	121
Cu	1.6	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.4	0.12
Fe	31*	21‡	26†	24†,‡	25†,‡	25†	25†	28*,†	23†,‡	25	1.6
K	3520	3600	3690	3580	3520	3650	3870	3510	3530	3620	135
Mg	1160	1200	1170	1070	1160	1210	1180	1180	1130	1170	55.0
Mn	5.1	4.7	5.6	5.2	5.2	5.2	5.6	5.3	5.4	5.3	0.28
Na	4.1	ND	4.3	7.1	5.9	ND	4.3	6.0	8.4	5.6	1.4
Ni	1.2	ND	1.4	1.4	0.7	1.8	ND	1.7	ND	ND	ND
P	2640	2860	2970	2940	2750	2820	3090	2730	3040	2880	1300
S	1260	1070	1060	1130	1060	1130	1070	1080	1130	1110	300
Zn	19	18	20	21	19	20	21	19	20	19	0.90

[a]Values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$). ND, not determined.

Table 3
Element Content of Beer From Dry-Grind Plants[a]

	Plant									Least squares mean	SE
	1	2	3	4	5	6	7	8	9		
Al	162	543	513	103	186	296	482	164	206	295	235
B	10.4*	10.5*	9.2*,†	8.7†	9.7*,†	10.5*	9.6*	9.9*	8.3†	9.6	0.52
Ca	406	366*,†	322†	306†	340†	322†	290‡	340†	310†	334	26
Cu	6.4	5.4	5.4	6.1	5.4	5.4	5.8	5.7	5.5	5.7	0.44
Fe	121	96	113	114	139	109	114	119	105	115	12
K	14,200	11,900	14,300	14,400	14,100	14,800	15,700	14,600	14,000	14,200	821
Mg	4290	3760	4440	4240	4470	4560	4630	4630	4090	4350	258
Mn	18.4†,‡	16.2‡	20.9†	19.8†	19.8†	21.0†	24.4*	20.8†	19.5*,†	20.1	1.2
Mo	0.5	1.0	0.8	0.8	0.8	0.6	0.90	0.8	0.6	0.9	0.10
Na	1600	1270	933	1550	1110	1190	706	1670	797	1200	297
Ni	1.4	1.3	1.6	1.8	1.4	1.9	1.8	1.8	1.6	1.6	0.20
P	9790†,‡	8500‡	10,600*,†	11,000*,†	9680†	10,600*,†	11,400*	10,300*,†	10,400*,†	10,200	605
S	5500†	5190†	7980*	3660†	6620*,†	7100*,†	8370*	5700†	6530*,†	6300	799
Sr	1.7*	1.0†	1.1†	0.8†	1.0†	0.9†	0.9†	1.6*	1.2*,†	1.1*,†	0.17
Zn	78	66	178	187	79	159	89	131	334	144	65

[a]Values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$).

into the beer well, mixed with stillage and eventually combined with DDGS. NaOH also may be used to adjust pH for optimum enzyme and yeast performance.

For several elements, there were differences among plants. For example, plant 1 had a higher Ca content of beer than most other plants. Plant 7 had the highest P content (11,400 mg/kg), whereas plant 2 had the lowest P concentration (8500 mg/kg). The wide range in P concentrations of beer among plants appeared to reflect differences in concentrations of P in corn (2680–3190 mg/kg; Table 1). Mean S content of corn was 1319 mg/kg (Table 1). Following the disappearance of starch owing to fermentation, the S content of beer should be about 4400 mg/kg (a threefold increase); however, beer from most plants had concentrations well in excess of the expected concentration. Presumably, increased S reflects the addition of S compounds (e.g., sulfuric acid) to adjust the pH for optimum enzyme activity during liquefaction or to meet yeast requirements during fermentation.

Wet Grains

Whole stillage was centrifuged (Fig. 1), resulting in two streams, wet grains and thin stillage. Wet grains contain unfermented particulate material, which consists of fiber, proteins, ash, and other components. In the present study, wet grains had much lower concentrations of most elements than did beer, suggesting that much of the element content of beer was carried in the liquid stream (thin stillage). This becomes especially evident when one compares the Na, P, and K concentrations of beer (1200, 10,200, and 14,200 mg/kg, respectively; Table 3) to the concentrations in wet grains (449, 5410, and 5370 mg/kg, respectively; Table 4). Concentrations of several elements, including Ca, Na, and Zn, were different among plants. However, concentrations of most elements, including P, were not different among processing plants.

Syrup

Syrup is produced when thin stillage is dewatered partially in a multiple-effect evaporator (Fig. 1). Although more concentrated than thin stillage, syrup contains significant amounts of water (solids content averaged 250 g/kg). Syrup is viscous and has high osmolarity, which makes complete removal of water difficult to achieve with conventional dewatering equipment. Therefore, syrup is added to wet grains to facilitate drying. During the centrifugation step in which whole stillage is separated into wet grains and thin stillage, many of the elements are carried into the aqueous fraction. This results in syrup having relatively high concentrations of many elements; in particular in the present study were mean concentrations of K, Mg, Na, and P (23,200, 6870, 2360, and 15,200 mg/kg, respectively; Table 5).

Concentrations of many elements in syrup were different among plants; these included Ca, K, Mg, Na, S, and Zn. P concentrations were not different among plants (Table 5). Because concentrations of these elements in corn were not different among plants, differences in syrup reflect differ-

Table 4
Element Content of Wet Grains From Dry-Grind Plants[a]

	Plant									Least squares	
	1	2	3	4	5	6	7	8	9	mean	SE
Al	32*,†	46*	19†,‡	14‡	13‡	21†	15‡	14‡	11‡	21	6.0
B	4.8	4.2	3.8	3.5	3.1	4.1	3.0	3.5	3.6	3.8	0.45
Ca	282*	187†	149‡	196†	143‡	201†	134‡	194†	177†,‡	185	16.0
Cu	6.0*	6.0*	4.8‡	5.5†	5.2†,‡	5.2†,‡	6.4*	5.0‡	5.0‡	5.4	0.2
Fe	109	153	74	15	66	90	66	123	95	102	30.0
K	6140	5160	5060	5110	4520	6060	5120	5220	5900	5370	654
Mg	2100	1780	1550	1680	1540	2090	1560	1880	1820	1780	194
Mn	12.7	10.7	9.5	10.9	9.4	11.7	9.3	12.2	10.5	10.8	1.0
Na	651*	478†	368†,‡	574*	399†	463†	252‡	515*,†	339†,‡	449	70.0
Ni	0.8	0.6	0.7	0.7	0.6	0.9	0.8	0.7	0.7	0.70	0.10
P	5620	5600	5250	5060	4830	5920	5290	5280	5810	5410	354
S	4770	5250	4890	4000	4780	5480	5700	4420	4860	4900	242
Sr	1.2	0.5	0.8	0.6	0.5	0.5	0.4	0.2	0.7	0.70	0.09
Zn	77	88	161	77	63	140	54	144	145	105	19

[a]Values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$).

Table 5
Element Content of Syrup From Dry-Grind Plants[a]

	Plant									Least squares mean	SE
	1	2	3	4	5	6	7	8	9		
Al	12.0	[b]	11.0	14.0	8.0	8.0	8.0	8.0	9.0	10.8	1.10
B	16.5	105.5	12.9	19.4	17.4	18.5	13.0	20.3	12.4	26.2	28.9
Ca	$480^{\dagger,\ddagger}$	572^{*}	$420^{\ddagger}$	$416^{\ddagger}$	$516^{*,\dagger}$	$492^{\dagger,\ddagger}$	$392^{\S}$	$411^{\ddagger}$	$421^{\ddagger}$	458	33.4
Cu	5.1	4.1	5.7	6.4	5.3	5.7	4.3	4.8	5.1	6.3	3.30
Fe	117	234	126	145	140	126	119	115	121	138	33.3
K	$23,800^{*,\dagger}$	$25,500^{*}$	$19,900^{\ddagger}$	$23,700^{*,\dagger}$	$25,600^{*}$	$26,300^{*}$	$21,300^{\dagger}$	$22,200^{*,\dagger}$	$20,700^{\dagger}$	23,200	1340
Mg	$6730^{*,\dagger}$	7730^{*}	$5970^{\dagger}$	$6790^{*,\dagger}$	7780^{*}	7570^{*}	$6270^{*,\dagger}$	$6970^{*,\dagger}$	$6000^{\dagger}$	6870	437
Mn	20.9	47.7	25.6	29.8	32.5	29.0	29.8	23.7	23.8	29.2	6.30
Mo	0.5	0.8[c]	0.8	0.9	0.7	0.5	0.6	0.8	0.8	0.8	0.02
Na	$2590^{\dagger,\ddagger}$	3360^{*}	$1800^{\ddagger,\S}$	$3110^{*,\dagger}$	$3130^{*,\dagger}$	$2420^{\dagger,\ddagger}$	$1200^{\S}$	$1930^{\ddagger}$	$1730^{\ddagger,\S}$	2360	305
Ni	2.6	22.3	2.3	3.3	3.0	3.3	2.4	3.0	2.4	4.9	0.90
P	14,000	15,400	15,300	18,700	15,100	15,400	13,700	16,000	13,600	15,200	1280
S	$2540^{\ddagger,\S}$	$13,200^{*}$	$7390^{\ddagger}$	$1970^{\S}$	$9460^{\dagger}$	$7500^{\ddagger}$	$10,700^{\dagger}$	$6370^{\ddagger}$	$7480^{\ddagger}$	7400	1830
Sr	1.8	11.7	1.4	1.1	1.7	1.2	1.3	1.4	1.8	2.6	3.40
Zn	$59^{\S}$	$110^{\dagger,\ddagger,\S}$	216^{*}	$106^{\ddagger,\S}$	$101^{\ddagger,\S}$	$165^{*,\dagger}$	$97^{\ddagger,\S}$	$146^{\dagger,\ddagger}$	$138^{\dagger,\ddagger}$	126	21.5

[a]Values (mg/kg dry basis [db]) followed by the same symbol in the same row did not differ significantly ($p < 0.01$).
[b]One sample had Al concentration of 579 mg/kg db which was deleted from statistical analysis.
[c]One sample had Mo concentrations of 528 mg/kg db which was deleted from statistical analysis.

ences in processing conditions among plants. One plant had high concentrations of Al, Mo, and Ni; the reasons for this are not clear.

Distillers' Dried Grains With Solubles

DDGS result from the blending and drying of syrup and wet grains (Fig. 1). In the mixing step, syrup is sprayed onto wet grains; the proportion of the two streams is not controlled tightly and can vary. The two streams are blended on a volume basis. The solids content of each stream can vary from batch to batch, and the element content of each stream can vary markedly. These three factors and their potential interactions provide the potential for the wide variation observed in DDGS element concentrations.

The concentrations of most elements in DDGS were lower than in syrup and higher than in wet grains (Table 6); this reflected differences in element concentrations of the latter two streams and was suggestive of DDGS containing more wet grains than syrup on a dry basis. Among plants, there were differences in the concentrations of many elements (Table 6). For example, the Ca content of DDGS from plant 7 was 247 mg/kg, compared with 339 mg/kg for plant 1. Phosphorus varied from 7110 mg/kg for plant 1 to 9430 mg/kg for plant 7. S concentrations ranged from 3800 mg/kg for plant 1 to 8270 mg/kg for plant 7.

The variation in element content of DDGS noted in the present study has been documented by others *(1,3,7–9)*. However, this is the first time variation within and among ethanol plants has been examined. The element content of corn was not different among plants, and plants used similar processing equipment to convert corn into ethanol and DDGS. This infers that variations in element contents of DDGS among plants must reflect differences in processing techniques and conditions.

Comparison of Dry-Grind Streams

There were differences among streams for mean concentrations of many elements (Table 7); therefore, some streams have higher element contents than others. The concentrations of most elements in beer were three times those of corn, due to the concentrating effect of the disappearance of starch during fermentation. Syrup had the highest element concentrations, presumably because during separation of whole stillage a large proportion of elements was carried into the aqueous stream and ended up in syrup. This resulted in lower element concentrations in wet grains. These data are suggestive that additional processing could reduce element content of DDGS, including beer, whole stillage, thin stillage, and syrup.

Processing of beer could have certain advantages. For example, it could reduce the amount of water that the evaporators must remove, reducing energy costs. Furthermore, it could remove some inorganic compounds, which contribute to scale buildup and fouling. However, the volume of material to be processed would be large, and the particulate matter in beer could impede separation. Whole stillage has the same limitations as those associated with beer, except solids content would be higher. Syrup has high

Table 6
Element Content of Distillers Dried Grains With Solubles (DDGS) From Dry Grind Plants*

	Plant									Least squares mean	SE
	1	2	3	4	5	6	7	8	9		
Al	18*	11[‡,§]	9[§]	15[*,†]	16[*,†]	13[†,‡]	15[*,†]	13[†,‡]	10[‡,§]	13	2.10
B	7.1[‡]	8.9*	6.9[‡,§]	7.0[‡,§]	7.1[‡]	8.5[*,†]	7.7[†,‡]	6.5[‡]	6.8[‡]	7.4	0.4
Ca	339*	323[*,†]	259[‡]	278	263*	299[†,‡]	247[‡]	263[‡]	268	282	13.0
Cu	6.1	6.8	4.9	5.6	5.7	5.3	6.0	4.9	5.3	5.6	0.50
Fe	101	109	96	105	94	100	96	97	90	99	4.10
K	9310[§]	12,300[*,†]	10,900[‡]	11,300[‡]	11,500[†,‡]	12,100[*,†]	12,400*	9780[§]	11,400[†,‡]	11,200	308
Mg	2990[§]	3790[*,†]	3330[‡]	3320[‡]	3580[†,‡]	3790[*,†]	3730*	3340[§]	3440[†,‡]	3480	97.2
Mn	15.6[‡]	17.0[†,‡]	15.7[‡]	17.4[†]	17.6[†]	17.7[†]	19.3*	15.9[‡]	16.5[†,‡]	17.0	0.50
Mo	5.8	12.2	0.9	1.1	1.0	0.8	1.1	1.1	0.8	3.3	4.90
Na	1120[‡]	2300*	1350[‡]	1980[†]	1170[‡]	1240[‡]	601[§]	1040[‡,§]	869[‡,§]	1300	212
Ni	10.4	23.4	3.2	3.6	1.6	2.6	4.0	2.8	3.6	6.2	7.10
P	7110[§]	8760[‡]	8560[‡]	8800[‡]	8550[‡]	8990[†,‡]	9430*	7510[§]	8940[‡]	8520	212
S	3800[‡]	6580[†]	6310[†]	3440[‡]	5740[‡]	6040[†]	8270*	5620[†]	6090[†]	5770	645
Se	11.7	14.7	11.4	11.4	18.3	9.7	12.0	11.5	11.6	12.8	3.00
Sr	1.6*	1.0[†,‡]	1.1[*,†]	0.9[†,‡]	0.8[†,‡]	0.7[‡]	0.9[†,‡]	1.6*	1.1[†]	1.1	0.10
Zn	78[‡]	79[‡]	155[†]	88[‡]	77[‡]	161*	75[‡]	140[†]	170*	114	6.00

[a]Values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$).

Table 7
Comparison of Element Concentrations of Streams[a]

	Corn	Beer	Wet grains	Syrup	DDGS
Ca	51‖	334†	185§	458*	282‡
Cu	1.6‡	5.7†	5.4†	6.3*	5.6†
Fe	35§	115†	102‡	138*	99‡
K	3590‖	14,200†	5370§	23,200*	11,200‡
Mg	1130‖	4350†	1780§	6870*	3480‡
Mn	5.5‖	20.1†	10.8§	29.2*	17.0‡
Na	5.4§	1200†	449‡	2360*	1300†
Ni	1.0†	1.6†	0.7†	4.9*	6.2*
P	2910‖	10,200†	5410§	15,200*	8520‡
S	1320‖	6300†	4900§	7400*	5770‡
Zn	19‡	144*	105†	126*	114†

[a]Least squares means; values (mg/kg dry basis) followed by the same symbol in the same row did not differ significantly ($p < 0.01$).

element concentrations and does not contain particulate matter, which could be advantageous over beer or whole stillage. However, high solids content, high osmolarity, and high viscosity could make additional processing extremely difficult and essentially render syrup unsuitable for modification. Thin stillage, the parent stream of syrup, has high water content and high element content and, like syrup, contains relatively low amounts of particulate matter; it appears to be the most logical stream for additional processing to remove both water and elements.

Processing technologies are being developed and/or improved to modify high water-processing streams. One technology with potential is membrane filtration. The primary objective of membrane filtration is to remove water from high water streams without the use of heat. Current technologies used for water removal from dry-grind process streams (multieffect evaporators and dryers) involve the use of high temperatures and a physical change of state (liquid to vapor). There are disadvantages to this approach: heating requires considerable amounts of energy, which adds to operational costs; and high temperatures adversely affect protein quality. Centrifugation and membrane filtration can eliminate these disadvantages. Centrifugation and membrane filtration equipment require 4–7 and 7–110 kJ/kg of water removed from the coproduct stream, respectively. By contrast, modern evaporation and drying equipment require inputs of 300–3000 kJ/kg of water removed from the DDGS coproduct streams, an energy input increase of 3- to 400-fold over centrifugation and filtration methods *(10)*. As a general rule, the initial 90% of water to be removed by dewatering requires approx 5% of the energy input; the remaining 10% of water to be removed by drying requires 95% of the total energy input to increase solids content from 10 to 90%. Therefore, dewatering technologies should be considered an important part of reducing energy inputs for the production of ethanol.

Membrane filtration can remove significant amounts of water from the gluten processing streams from corn wet milling *(11)*. We also found that much of the ash in several processing streams from wet milling was recovered in the permeate *(12)*. Thus, it seems possible that membrane filtration could remove water and elements in high water streams found in dry-grind processing. More efficient methods of water removal have economic implications for dry-grind processing. Present methods are costly and have high maintenance requirements (cleaning of fouled surfaces); reducing or eliminating current methods could improve processing efficiency. In addition, it might be possible to remove significant amounts of elements in the water stream. This could reduce the element contents of DDGS, especially P and S, to levels that are more consistent with animal requirements, thereby reducing potential waste disposal concerns.

Comparison of Study Data With Published Data

Table 8 compares the element composition of corn and of DDGS in the present study to published data *(13)*. It is a commonly held belief in corn-processing industries that the element content of corn has changed during the past approx 20 yr due to focused breeding programs. Samples of corn obtained in the present study were taken from dry-grind plants located in different regions of the upper Midwest. Presumably, they were exposed to a wide range of agronomic and growing conditions and included a variety of corn hybrids and sources. Despite such apparent heterogeneity, the concentrations of most elements in corn, including P, were not different among dry-grind plants (Table 1). Furthermore, element concentrations in corn in the present study were similar to published data (Table 8). These data corroborate an earlier study in which we reported that the composition of corn sampled during a 5-yr period varied little and was similar to published data. In addition, variation in the composition of DDGS was not correlated with variation in the composition of corn *(14)*. The concentrations of most elements, including P, at least in commercially grown corn have changed little during the past several decades and variation in DDGS composition is due to processing conditions, rather than corn *per se*.

Unlike corn, many elements in DDGS in the present study were different from published data. DDGS had higher concentrations of K, Mg, and P and a lower concentration of Na than published sources *(13)*. The source of DDGS in the highly referenced National Research Council source *(13)* is not known; the data could have originated from beverage ethanol or corn wet-milling industries. Processing conditions in these industries differ from dry-grind processing and could explain at least some of the differences. An important effect of the disparity between published/historical analytical data and contemporary data is that computer programs used to formulate diets may use published data rather than contemporary data. This problem is exacerbated by a lack of published data for DDGS produced by dry-grind plants.

Table 8
Comparison of Element Concentrations of Corn and DDGS[a]

	Corn		DDGS	
	This study	NRC	This study	NRC
Ca	51	30	282	115
Cu	1.6	4	5.6	89
Fe	35	30	99.0	610
K	3590	3700	11,200	4400
Mg	1130	1400	3480	1800
Mn	5.5	5.0	17.0	25.0
Na	5.4	30.0	1300	3300
P	2910	2900	8520	7100
Zn	19	14	114	60[b]

[a]Values are given as mg/kg of dry basis.
[b]Estimated from Zn content of dried grains and solubles *(13)*.
NRC, National Research Council.

Conclusion

The concentrations of most elements in corn did not vary among processing plants. However, for other processing streams there were differences in element concentrations among plants. The source of the variation is not clear but variation in processing conditions is a primary cause. Although syrup had the highest element concentrations, it would be difficult to process. To reduce the element content of DDGS, thin stillage (the parent stream for syrup) appeared to be the most logical stream for processing. It might be possible to use membrane filtration to remove both water and elements in process streams.

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