

Characterization of light gluten and light steep water from a corn wet milling plant

K.D. Rausch^a, C.I. Thompson^a, R.L. Belyea^{b,*}, M.E. Tumbleson^c

^a Department of Agricultural Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

^b Department of Animal Sciences, 115 ASRC, University of Missouri, 920 East Campus Drive, Columbia, MO 65211, USA

^c Veterinary Biosciences, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

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Abstract

The primary commodity of corn wet milling is starch, but two coproducts (corn gluten feed, CGF and corn gluten meal, CGM) also are produced. CGM and CGF are marketed as animal foodstuffs and are important economically; however, variation in composition reduces quality. There are few data on the effect of composition of the parent process streams, light steep water (LSW) and light gluten (LG), respectively, on composition of CGF and CGM. The objective was to characterize LG and LSW. Samples of LG and LSW were collected: (1) hourly for one day, (2) every 3 h for 3 days, and (3) daily for 3 weeks. Dry matter, N and ash were determined. Variation in composition of LG and LSW was greatest during longer periods of time (days and weeks) rather than shorter (hourly or every 3 h). There was significant variation in DM (solids) content, which directly affected the concentration of other components. Variation in N (protein) of LG and LSW accounted for much of the variation in CGF and CG. Processes that modify processing and reduce variation could increase the quality of CGF and CGM.

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1. Introduction

The primary product from the wet milling of corn is starch, which is used to make ethanol, lactic acid, amino acids and high fructose syrup. Two major coproducts, corn gluten feed (CGF) and corn gluten meal (CGM), also are produced. CGF and CGM add value to and reduce the cost of corn processing, but there can be substantial variation in their composition, which reduces quality and market value. In previous work, we showed that the protein content of distillers solubles, a process stream in ethanol production, varied from 18% to 22% (dry basis). This variation affected the protein content of distillers dried grains with solubles, of which distillers solubles is a major component (Belyea et al., 1998).

We have reported that the protein content of CGF varied from 22% to 26% (Belyea et al., 1989); however, it is possible for some batches of CGF to be as low as 18%

or as high as 30%. If a batch of CGF contained 26% protein and were sold on the assumption that protein content was 20% (to meet minimum label specifications), full market potential of the CGF would not be realized. In addition, animals could be consuming excessive protein, which is costly and could contribute to N pollution (NRC, 1985). Reducing variation in composition, particularly protein, could increase the market value of CGF and CGM.

CGF and CGM are formed from two process streams, light steep water (LSW) and light gluten (LG), respectively. LSW is the liquid drained from the steep tanks after steeping has been completed and contains primarily soluble proteins and carbohydrates (Wright, 1987). After being concentrated, LSW is mixed with corn fiber and germ meal and dried to form CGF (Singh et al., 2001), which is fed to ruminants. LG contains primarily endosperm proteins; it is concentrated and dried to form CGM (Wright, 1987). CGM has high protein content and is fed to nonruminants. Variation in the composition of the parent streams, LSW and LG, could affect the composition of the resultant coproduct streams, CGF and CGM, respectively. However, there

* Corresponding author. Tel.: +1-573-882-6354; fax: +1-573-882-6827.

E-mail address: belyear@missouri.edu (R.L. Belyea).

are few published analytical data on the composition of the former (Wright, 1987). The objective was to obtain characterization data for LG and LSW.

2. Methods

Collection of experimental material. Samples of LG and LSW were obtained from a commercial corn wet milling plant by University of Illinois (Urbana-Champaign) scientists and shipped overnight (on ice) to the University of Missouri (Columbia) for analyses. The plant used typical dent corn obtained from commercial corn growers in the region. Specific processing details were proprietary information of the company; however, in a typical wet milling process, steep tanks are drained at the end of steeping for 24–36 h, and the resulting LSW is transferred to evaporators. The LSW samples in this study were collected from the process line leading from the steep tanks to the evaporators. The LG samples were collected from the process line leading from the light gluten storage tank to the gluten centrifuges. Three sets of samples of LG and LSW were obtained for characterization.

Measurement of storage effects. Sample set one (hourly samples) was collected hourly from 10:00 a.m. to 2:00 p.m. over a single day to provide initial analytical data and to determine effects of storage on composition. When the samples were received at the University of Missouri, they were subsampled immediately; one subsample was frozen and the second was refrigerated. Analyses were completed on the latter within 1 day of receipt (2 days after procurement). Measurements that did not repeat (which were minimal) were redone the next day. Thus, all analyses were completed within 3 days of procurement (most were within 2 days). To determine if changes occurred during refrigeration, procedures were repeated 7 days after receipt (9 days after procurement). Finally, frozen subsamples were thawed after 14 days in storage and analyzed to determine effects of storage while frozen.

Measurement of within day variation. For sample set two (within days), samples were collected every 3 h over a 3-day period to determine short term variation in composition of LG and LSW. Samples were collected as described above, kept on ice during procurement and shipping and refrigerated during analyses. Analytical procedures were completed within 7 days of receipt.

Measurement of among day variation. For sample set three (among days), samples were collected once daily during three different periods of 4–5 days each to determine long term variation in chemical composition. Samples were collected and handled as described for the previous samples.

Analytical procedures. Dry matter (DM, solids) were determined by drying in a convection oven at 105 °C for

24 h. Total nitrogen (TNw) was determined on the as is (wet) samples by thermal conductivity (Leco, 1994); total N was corrected to a dry basis (TNd = TNw/DM). Total suspended solids (TSS) were determined by measuring dried solids retained on fiberglass filters with 1.2 µ dia openings. Soluble nitrogen (SN) was determined by filtering a subsample through a 45 µ microdisk and determining N in the filtrate. Ash (Ashw) was measured as weight loss of the as is (wet) samples when placed in a muffle furnace at 550 °C for 12 h; Ashw was corrected to a dry basis (Ashd = Ashw/DM). Organic matter (OM) was calculated as 100 – Ashd.

Statistical analyses. Data were analyzed as a simple block design using SAS (1985) procedures; a general linear model was used to test main effects. Means (as least significant means) were compared by least significant difference, when main effects were significant ($P < 0.05$).

3. Results and discussion

Effects of storage on composition of LG and LSW are presented in Table 1. Day (of analysis) had some effects on composition of both streams. For LG, mean DM concentration on day 2 (4.85 g/100 g) was higher than on day 9 (4.45 g/100 g); concentrations of TNw, TNd and TSS on day 9 (0.630, 14.28 and 8.21 g/100 g) were higher than on day 2 (0.500, 10.30 and 3.13 g/100 g, respectively). For LSW, changes from day 2 to day 9 were similar to those noted for LG. DM content of LSW decreased from day 2 to day 9, while TNw, TNd and TSS increased (Table 1). For both LG and LSW, the decrease in DM concentration and increase in TN concentration with time in storage (Table 1), although small, were statistically significant and difficult to explain. The decrease in DM could be the result of a small amount of enzymatic or microbial degradation of components, such as starch. If this were true, however, there should be a corresponding increase in ash, which did not occur. Furthermore, this would not explain the increase in TN.

These data indicated that the time lapse from sample acquisition to analysis should be minimal. Samples should be kept either on ice or under refrigeration during procurement, shipping and analyses. If analyses are completed within 9 days or less (preferably within 2–3 days), the effects on DM, TNw, TNd, Ashw, Ashd and OM content of LG and LSW appear to be minimal. However, TSS should be measured immediately. Freezing did not affect DM, TNw or Ashw concentrations (data not shown), and this is an alternative, if analytical procedures cannot be carried out immediately.

Short term (within days) analytical data for LG and LSW are presented in Table 2. Day of sampling had

Table 1
Effect of storage time on composition of LG and LSW samples

| Day ^a | Time ^b | DM ^c | TNw ^d | TNd ^d | SN ^e | TSS ^f | Ashw ^g | Ashd ^g | OM ^h |
|------------------|-------------------|-----------------|------------------|------------------|-----------------|------------------|-------------------|-------------------|-----------------|
| LG | | | | | | | | | |
| 2 | 1000 | 5.08 | 0.543 | 10.69 | 23.8 | 3.26 | 0.26 | 5.12 | 94.44 |
| | 1100 | 5.02 | 0.524 | 10.44 | 22.2 | 3.33 | 0.48 | 9.56 | 90.44 |
| | 1200 | 4.77 | 0.493 | 10.34 | 22.1 | 3.19 | 0.33 | 6.92 | 93.08 |
| | 1300 | 4.81 | 0.471 | 9.79 | 23.6 | 2.97 | 0.33 | 6.86 | 93.13 |
| | 1400 | 4.58 | 0.471 | 10.28 | 23.9 | 2.91 | 0.30 | 6.55 | 93.45 |
| | Mean | 4.85a | 0.500b | 10.30a | 23.1 | 3.13a | 0.34 | 7.00 | 93.00 |
| 9 | 1000 | 4.75 | 0.616 | 12.97 | – | 8.57 | 0.30 | 6.32 | 93.68 |
| | 1100 | 4.23 | 0.652 | 15.41 | – | 8.91 | 0.27 | 6.38 | 93.61 |
| | 1200 | 4.54 | 0.627 | 13.81 | – | 8.11 | 0.35 | 7.70 | 92.29 |
| | 1300 | 4.55 | 0.628 | 13.80 | – | 8.17 | 0.40 | 8.79 | 91.21 |
| | 1400 | 4.16 | 0.640 | 15.38 | – | 7.29 | 0.30 | 7.21 | 92.79 |
| | Mean | 4.45b | 0.630b | 14.28b | – | 8.21b | 0.32 | 7.28 | 92.70 |
| | SE ⁱ | 0.10 | 0.011 | 0.36 | – | 0.20 | 0.03 | 0.60 | 0.60 |
| LSW | | | | | | | | | |
| 2 | 1000 | 10.95 | 0.793 | 7.24 | 73.2 | 4.35 | 2.04 | 18.63 | 81.37 |
| | 1100 | 10.82 | 0.772 | 7.13 | 77.7 | 4.25 | 2.04 | 18.85 | 81.14 |
| | 1200 | 10.92 | 0.739 | 6.77 | 71.4 | 3.42 | 1.96 | 17.95 | 82.05 |
| | 1300 | 10.87 | 0.770 | 7.08 | 69.0 | 4.61 | 1.91 | 17.57 | 82.43 |
| | 1400 | 10.82 | 0.957 | 8.84 | 70.1 | 4.30 | 1.90 | 17.56 | 82.44 |
| | Mean | 10.87a | 0.806a | 7.41a | 72.3 | 4.19a | 1.97 | 18.11 | 81.89 |
| 9 | 1000 | 10.56 | 0.959 | 9.08 | – | 8.89 | 1.99 | 18.84 | 81.16 |
| | 1100 | 10.56 | 0.928 | 8.79 | – | 8.24 | 2.22 | 21.03 | 78.98 |
| | 1200 | 10.51 | 0.927 | 8.82 | – | 9.03 | 1.99 | 18.93 | 81.07 |
| | 1300 | 10.38 | 0.964 | 9.29 | – | 7.95 | 1.98 | 19.08 | 80.92 |
| | 1400 | 10.46 | 0.942 | 9.01 | – | 9.28 | 1.91 | 18.26 | 80.92 |
| | Mean | 10.49b | 0.942b | 9.00b | – | 8.68b | 2.02 | 19.23 | 80.77 |
| | SE | 0.30 | 0.027 | 0.267 | – | 0.227 | 0.043 | 0.383 | 0.383 |

ab: Within column and parameter, means with unlike letters differ ($P < 0.01$).

^a Day of analytical measurements relative to day of sampling.

^b Hour of sample day that sample was collected.

^c DM = dry matter (solids); g/100 g.

^d TNw = total N on wet basis (g/100 g); TNd = total N on a dry basis (g/100 g).

^e SN = soluble N (g/100 g TN).

^f TSS = total suspended solids (g/100 ml).

^g Ashw = ash on wet basis (g/100 g); Ashd = ash on a dry basis (g/100 g).

^h OM = organic matter (100 – Ashd).

ⁱ SE = standard error.

some significant effects. For LG, DM was higher for days 2 and 3 than day 1. For LSW, DM was lower on day 2 than day 1 and was lower on day 3 than day 2. TNw and Ashw were lower on days 2 and 3 than day 1, while Ashd was higher on days 2 and 3 than day 1. TNd was higher on day 2 than days 1 and 3. Hour of sampling did not have significant effects on composition of either LG or LSW (Table 2). The variation in DM, TNw and TNd concentrations of LG and LSW across the 72 h sampling period are presented in Figs. 1 and 2, respectively. For LG, DM was quite variable, but there was little increase or decline during the sampling period. For LSW, variation in DM from sample to sample was relatively small, but there was a general decline during the 72 h sampling period. For LG (Fig. 1), patterns for TNw and TNd were similar to each other and to that of DM. For LSW (Fig. 2), TNd and TNw exhibited similar

patterns for approximately the first 24 h period. After that, TNw declined while TNd increased. This reflected the concurrent decrease in DM (TN became more concentrated).

There were some long term effects on composition of LG (Table 3). DM, TNw and TSS were lower in week 3 than weeks 1 and 2; TNd was lower in weeks 2 and 3 than week 1. The variation in mean TNd from week 1 to week 3 (10.03–9.62%) markedly affected the protein equivalent ($\text{TNd} \times 6.25 = 62.6\%$ to 59.3%). There were no significant long term effects on the composition of LSW (Table 3).

Variation in DM% affected the concentrations of other nutrients in LSW and LG. During week 1 of long term sampling (Table 3), DM of LSW varied 1.14% units (from 9.86% to 11.00%), which was equal to about 11% of the mean. Variation in dry matter concentration

Table 2
Short term (within day) variation in composition^a

| | LG | | | | | LSW | | | | |
|-------------------|-------|-------|-------|-------|-------|--------|--------|-------|-------|--------|
| | DM | TNw | TNd | Ashw | Ashd | DM | TNw | TNd | Ashw | Ashd |
| Day ^b | | | | | | | | | | |
| 1 | 4.35a | 0.415 | 9.51 | 0.35 | 8.08 | 10.08a | 0.702a | 6.97a | 1.74a | 17.21a |
| 2 | 4.83b | 0.457 | 9.45 | 0.40 | 8.34 | 8.68b | 0.571b | 6.58b | 1.55b | 17.92b |
| 3 | 4.84b | 0.450 | 9.46 | 0.38 | 8.65 | 8.19c | 0.585b | 7.14a | 1.45b | 17.71b |
| SE | 0.14 | 0.019 | 0.31 | 0.036 | 0.477 | 0.19 | 0.012 | 0.102 | 0.037 | 0.231 |
| Hour ^c | | | | | | | | | | |
| 1500 | 4.80 | 0.476 | 9.92 | 0.39 | 8.12 | 9.52 | 0.622 | 6.53 | 1.67 | 17.58 |
| 1800 | 4.72 | 0.437 | 9.27 | 0.46 | 9.77 | 9.62 | 0.661 | 6.86 | 1.67 | 17.42 |
| 2100 | 4.68 | 0.456 | 9.62 | 0.24 | 7.33 | 9.32 | 0.640 | 6.86 | 1.62 | 17.39 |
| 2400 | 4.27 | 0.419 | 9.77 | 0.39 | 9.18 | 8.94 | 0.609 | 6.82 | 1.60 | 17.92 |
| 300 | 4.79 | 0.386 | 8.16 | 0.36 | 7.53 | 8.88 | 0.593 | 7.01 | 1.55 | 17.42 |
| 600 | 4.63 | 0.447 | 9.70 | 0.45 | 9.63 | 8.21 | 0.592 | 7.19 | 1.42 | 17.39 |
| 900 | 4.52 | 0.444 | 9.78 | 0.34 | 7.56 | 8.51 | 0.592 | 7.00 | 1.54 | 18.19 |
| 1200 | 4.99 | 0.479 | 9.57 | 0.39 | 7.75 | 8.85 | 0.612 | 6.91 | 1.56 | 17.60 |
| SE | 0.278 | 0.032 | 0.454 | 0.053 | 0.615 | 0.589 | 0.045 | 0.220 | 0.094 | 0.450 |

ab: Within day and column, means with unlike letters differ ($P < 0.05$).

^a For explanation of headings, see Table 1.

^b Day of sampling.

^c Hour of sampling within day.

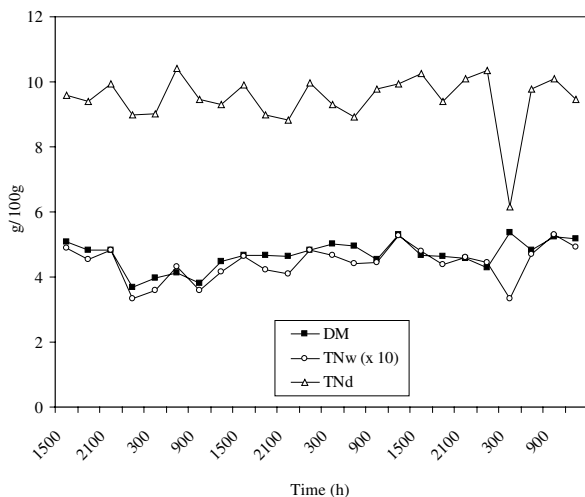


Fig. 1. Short term variation in composition of light gluten samples ((■) DM = dry matter; (○) TNw = total nitrogen times 10, wet basis; (△) TNd = total nitrogen, dry basis).

of this magnitude will affect concentrations of other nutrients in LSW. In week 1, when N was expressed on wet basis (TNw), variation was 0.083% units (0.783–0.700%); this was equal to about 11% of the mean. When expressed on a DM basis (TNd), variation was reduced to about 6% of the mean. For LG, there were similar effects. An important relationship to note is that TNw concentrations were not necessarily directly related to TNd concentrations. For example, the highest N concentration on a wet basis (TNw) was 0.808% (day 4 of week 3, Table 3), while the highest N concentration on a dry basis (TNd) was 7.63% (day 1 of week 3). These

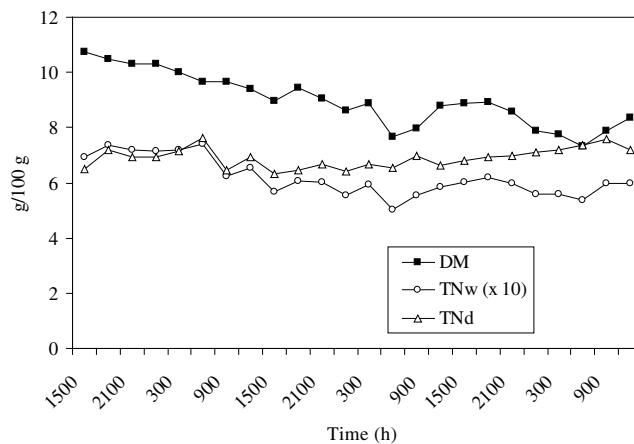


Fig. 2. Short term variation in composition of light steepwater samples ((■) DM = dry matter; (○) TNw = total nitrogen times 10, wet basis; (△) TNd = total nitrogen, dry basis).

data point out that comparing the N content of samples of LSW and LG on a wet basis (TNw) can be misleading, because variation among samples can be due to differences in DM content as well as true differences in N content (on a water free basis). Without a DM measurement for correction, it is impossible to separate the effects. Even though variation was reduced when TN was expressed on a DM basis, the amount of variation in TNd (about 15%) was sufficient to have an adverse effect on nutritional quality and market value. Because N (protein) is the most important component (nutritionally and economically) in LSW (and LG), N content of coproduct streams should be determined on a dry as well as wet basis when composition is being evaluated.

Table 3
Long term variation in composition^a

| Week ^b | Day ^c | LG | | | | LSW | | | |
|-------------------|------------------|-------|--------|--------|-------|-------|-------|------|------|
| | | DM | TNw | TNd | TSS | DM | TNw | TNd | TSS |
| 1 | 1 | 4.80 | 0.520 | 10.83 | 1.86 | 10.7 | 0.727 | 6.79 | 0.64 |
| | 2 | 5.01 | 0.522 | 10.42 | 1.86 | 11.0 | 0.767 | 6.97 | 0.74 |
| | 3 | 5.31 | 0.524 | 9.87 | 2.02 | 10.9 | 0.783 | 7.18 | 0.84 |
| | 4 | 5.11 | 0.515 | 10.08 | 2.20 | 9.86 | 0.700 | 7.10 | 0.75 |
| | Mean | 5.06a | 0.520a | 10.03a | 1.99a | 10.62 | 0.744 | 7.01 | 0.74 |
| 2 | 1 | 5.47 | 0.524 | 9.58 | 2.13 | 10.83 | 0.784 | 7.24 | 1.08 |
| | 2 | 5.00 | 0.504 | 10.08 | 2.00 | 10.19 | 0.702 | 6.89 | 0.59 |
| | 3 | 4.73 | 0.441 | 9.32 | 1.85 | 9.89 | 0.690 | 6.98 | 0.66 |
| | 4 | 5.07 | 0.471 | 9.29 | 2.13 | 9.33 | 0.624 | 6.86 | 0.54 |
| | 5 | 6.04 | 0.553 | 9.16 | 2.39 | 9.98 | 0.624 | 6.25 | 0.58 |
| | Mean | 5.26a | 0.499a | 9.48b | 2.10a | 10.04 | 0.688 | 6.84 | 0.69 |
| 3 | 1 | 3.93 | 0.376 | 9.57 | 1.73 | 9.91 | 0.738 | 7.45 | 0.67 |
| | 2 | 4.48 | 0.436 | 9.73 | 1.69 | 9.87 | 0.576 | 5.84 | 0.61 |
| | 3 | 4.44 | 0.435 | 9.80 | 1.42 | 9.89 | 0.696 | 7.04 | 0.50 |
| | 4 | 5.10 | 0.478 | 9.37 | 1.59 | 11.71 | 0.808 | 6.90 | 0.93 |
| | Mean | 4.48b | 0.431b | 9.62b | 1.61b | 10.35 | 0.705 | 6.81 | 0.68 |
| | SE | 0.20 | 0.017 | 0.17 | 0.08 | 0.31 | 0.03 | 0.21 | 0.08 |

ab: Within column, means with unlike letters differ ($P < 0.05$).

^a Terms described in Table 1.

^b Week = week of sampling.

^c Day = day of sampling within week.

CGF consists of LSW and corn bran (fiber); variation in protein content of CGF could be due to variation in the protein content of either LSW or fiber and/or to variation in the proportion of LSW to fiber. Recently, we reported that the protein content of CGF varied from about 21% to 25% (mean = 23%, Belyea et al., 1989). In the present study, the protein content (TNd \times 6.25) of LSW varied among days from about 41% to 45% (mean = 43%, Table 2). If there were no variation in the protein content of corn fiber, variation in protein content of LSW alone could account for all of the variation in protein content of CGF. If one assumes that the mean protein concentration of LSW is 43% (Table 2) and that corn bran has a protein content of 9% (NRC, 1971), the ratio of LSW: fiber would have to be 40:60 to result in a protein content of 23% in CGF. If the ratio decreased to 30:70 or increased to 50:50, the protein content of CGF could decrease to 18% or increase to 25%, respectively. It is difficult to combine LSW and corn fiber in consistent proportions when CGF is being produced. Therefore, variation in protein content of CGF could be due to the proportion of LSW to fiber as well as to variation in protein content of LSW and corn fiber. The relative contribution of each source cannot be precisely determined from our data, but it seems likely that much of the variation in the protein content of CGF could be reduced if the variation in the protein (TNd) of LSW could be minimized.

To reduce analytical errors, it would be preferable to remove water from samples of LG and LSW prior to

analyses. This could be accomplished by lyophilization or by drying in an oven at a low temperature (70 °C or less). The latter approach might alter protein structure and/or drive off volatile compounds, which could affect certain measurements. Lyophilization circumvents these problems but is time consuming and expensive. In applied situations (industry), samples usually are analyzed as is (wet) rather than dry, because data often are needed immediately to evaluate processing conditions. Data expressed on a wet basis may agree reasonably well with that expressed on a dry basis much of the time, but sometimes they may not agree, which could lead to incorrect interpretations. A good example is TNw versus TNd of LSW (Fig. 2); during the later samples, when DM gradually decreased, TNd concentrations increased while TNw concentrations were uniform. Thus, TNw measurements alone could be misleading.

From a nutritional point of view, LSW has an interesting profile. On a dry basis, LSW contained about 18% ash and 43% protein. The fiber content of LSW was negligible, while the fat content probably would be about 2%. The remainder (37% = 100 - (18 + 43 + 2)) would most likely be nonfibrous carbohydrate (starch and/or monosaccharides). Wu (1998) found that the nonfibrous carbohydrates in CGF included 53% glucose, 15% arabinose, 15% xylose, 12% glycerol and 5% other sugars. We presume the carbohydrate fraction of LSW in the present study would have a similar distribution of monosaccharides; if so, the carbohydrate fraction of LSW could be very rapidly fermented by

bacteria in the digestive tract of ruminants (Van Soest, 1982). Excessive amounts could result in digestive upsets (Van Soest, 1982).

The ash content of LSW (~18%) is high and variable. While ash contains minerals that are important nutritionally, excessive ash displaces organic matter (energy and protein), which reduces quality. A major portion of ash is P and K; the concentrations of P and K in CGF are high relative to dietary requirements of animals. The high concentration of P in CGF is of particular concern, because it could result in excessive amounts of P in animal wastes. Reducing P and K (and ash) would increase other components, such as protein and energy. We assume that much of the P and K (and ash in general) in CGF arises from the LSW, because of the solubles in germ (Wright, 1987). Therefore, identifying alternatives to reduce the ash, in general, and the P and K in LSW, in particular, could have significant economic and environmental benefits.

Variation in protein and fiber content in CGF affects potential market value. Corn and soybean meal presently have US market prices of about \$12 and \$15 per 100 kg, respectively (Byproduct Feed Bulletin Board, 2003). On a comparative basis, CGF with a protein content of 18 g/100 g would have a market value of about \$10/100 kg. If the protein content were increased to 24 g/100 g, the market value of CGF would increase to about \$14/100 kg (Byproduct Feed Bulletin Board, 2003). Thus, variation in protein content often results in CGF being sold below potential market value to meet minimum specifications; this costs the corn wet milling industry a substantial amount of money.

4. Conclusion

The composition of LG and LSW did not vary greatly over short periods of time (from hour to hour or day to day). Over longer periods of time, there was significant variation in composition of LG but not LSW. Variation in dry matter (solids) was an important factor,

because of effects on other measurements. Variation in protein content of CGF could be due to composition of and/or proportion of the streams from which CGF is derived (LSW and corn fiber). Reducing the variation in protein content of LSW would reduce the variation in protein content of CGF.

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References

- Belyea, R.L., Steevens, B.J., Restrepo, R.R., Clubb, A.P., 1989. Variation in composition of by-product feeds. *J. Dairy Sci.* 72, 2339–2345.
- Belyea, R., Eckhoff, S., Wallig, M.A., Tumbleson, M., 1998. Variability in the nutritional quality of distillers solubles. *Biores. Tech.* 66, 207–212.
- Byproduct Feed Bulletin Board, 2003. Depts. of Agric. Econ. and Anim. Sci., University of Missouri, Columbia, MO.
- Leco, 1994. Leco N Determination Manual. Leco Corp., St Joseph, MI.
- NRC, 1971. Atlas of Nutritional Data on United States and Canadian Feeds. NAS, Washington, DC.
- NRC, 1985. Ruminant Nitrogen Usage. NAS, Washington, DC.
- SAS, 1985. Statistical Analysis System: Statistics. SAS Institute, Cary, NC.
- Singh, V., Rausch, K.D., Yang, P., Shapouri, H., Belyea, R.L., Tumbleson, M.E., 2001. Modified Dry Grind Ethanol Process. Departments of Agricultural Engineering, University of Illinois at Champaign-Urbana, UILU No. 2001–7021.
- Van Soest, P.J., 1982. Nutritional Ecology of the Ruminant. Durham and Downey, Portland, OR.
- Wright, K.N., 1987. Nutritional properties and feeding value of corn and its by-products. In: Watson, S.A., Ramstad, P.E. (Eds.), *Corn: Chemistry and Technology*. American Association of Cereal Chemists, St Paul, MN, p. 448.
- Wu, V., 1998. Neutral sugar contents of corn gluten feed and corn gluten meal. *J. Agric. Food Chem.* 44, 136–138.