Importance of Protein-Rich Components in Emulsifying Properties of Corn Fiber Gum

Madhav P. Yadav,1,2 Peter Cooke,1 David B. Johnston,1 and Kevin B. Hicks1

ABSTRACT

Purified corn fiber gum (CFG-F) isolated from fine (kernel endosperm-derived) corn fiber that contained ≤2% residual protein was extracted with 70% aqueous ethanol. The aqueous ethanol extract (AEE), which contained 19.5% of the total CFG, contained a high percentage of the proteinaceous material present in the original gum sample. The AEE gum contained 6.81% protein by weight. The residue (R), which constituted 66% of the total CFG-F, contained only 0.55% of protein. The emulsifying properties of R and AEE in a model oil-in-water emulsification system were studied by measuring turbidity after 1, 2, and 3 weeks, particle size after 4 weeks, and by confocal laser scanning microscopy after three months of storage at room temperature. These gums were compared with the standard well-known emulsifiers native acacia gum (NAG) and modified acacia gum (MAG). The results indicate that although AEE contains protein-rich components, it is not as good an emulsifier as the residue which contains only 0.55% of protein. However, emulsions prepared with the whole (unfractionated) CFG-F under similar conditions were more stable showing higher turbidity and smaller particles size than those prepared with either R or AEE.

MATERIALS AND METHODS

Materials

Oven-dried corn fiber samples were provided by ADM Research. They were ground to a 20-mesh particle size using a Wiley mill and de-oiled by extracting with hexane (Moreau et al. 1996). Starch was removed by heat-stable Termamyl α-amylase (Novozymes, Davis, CA) treatment (Doner et al. 1998).

Corn Fiber Gum (CFG) Extraction

CFG was extracted from de-oiled and de-starched corn fiber according to the alkaline hydrogen peroxide procedures of Yadav et al (2007a) with some modification. De-oiled and de-starched corn fiber (50 g) was mechanically stirred into water (1.0 L) and NaOH (12 g or 24 mL from 50% solution) and 42 mL of 30% H2O2 were carefully added in an open beaker in a fume hood. The mixture was boiled with efficient mechanical stirring for 1 hr. During the reaction, it was kept at pH 11.5 by adding 50% NaOH as needed. After cooling the hot reaction mixture by stirring at room temperature for an additional 0.5 hr, it was centrifuged at 6,000 x g for 20 min and the supernatant was separated from the residue by decantation. The alkaline H2O2 extract was then adjusted to pH 4.0–4.5 by adding conc. HCl to precipitate hemicellulose A (acid-insoluble arabinoxylan [Hemi. A]), which was collected by centrifugation at 10,000 x g for 30 min. Two volumes of ethanol (2.0 L) were gradually added to the supernatant (1.0 L) with stirring to precipitate the major arabinoxylan fraction, Hemi. B, (CFG). The CFG was allowed to settle out as a white flocculent precipitate at the bottom of the beaker for 10–15 min. The clear alcohol-water mixture above the precipitate was removed by decantation. The white flocculent precipitate was transferred into another beaker, stirred in 100% ethanol, and filtered under vacuum. The white residue obtained on the Buchner funnel was washed with 100% ethanol and dried in a vacuum oven at 50°C overnight.

Proximate Analysis

Protein (N x 6.25), moisture, and ash contents of corn fiber gums were determined according to Approved Methods 46-30, 44-19, and 08-01, respectively (AACC International 2000). The sodium and calcium contents of gum samples were determined by a standard atomic absorption method (Analytical Methods for Atomic Absorption Spectroscopy 1994).

1 Crops Conversion Science and Engineering Research Unit, Eastern Regional Research Center, Agricultural Research Service, USDA, 600 East Mermaid Lane, Wyndmoor, PA 19038. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

2 Corresponding author. Phone: 215 836-3783. Fax: 215 233-6559. E-mail address: madhav.yadav@ars.usda.gov

doi:10.1094/CCHEM-87-2-0089
This article is in the public domain and not copyrightable. It may be freely reprinted with customary crediting of the source. AACC International, Inc., 2010.
Separation of Protein-Rich Component

The protein-rich components of corn fiber gum were separated on the basis of solubility using a modified procedure of Dickey et al. (1998). CFG (10 g) was suspended in 250 mL of 70% ethanol and stirred at 60°C for 2 hr. The mixture was filtered under vacuum and the residue was resuspended in 70% ethanol (60°C hot), stirred for 5 min, and filtered. The residue on the Buchner funnel was washed with 70% ethanol (60°C hot) and 100% ethanol. All the extracts and washings were combined, evaporated to a small volume by rotary evaporation (50°C), and lyophilized. This extract is referred to as 70% aqueous ethanol extract (AEE). The residue (R) was dried in a vacuum oven at 45°C.

High-Performance Size-Exclusion Chromatography

A solution of 2 mg/mL of CFG was prepared for chromatography by slowly adding 20 mg of gum sample with vigorous stirring into 10 mL of 50 mM NaNO 3 solution (mobile phase for chromatography) at room temperature to make a homogeneous solution. The gum solution was dialyzed against 50 mM NaNO 3 1 L, (the dialysis solution was changed four times) using 6,000–8,000 MW cut-off dialysis tubing. The dialyzed solution was centrifuged at 50,000 × g for 10 min at 35°C and filtered through a 0.22-μm sterile Millex-HV filter (Millipore, Bedford, MA).

The chromatographic system consisted of high-performance size-exclusion columns and online molar mass and viscometer detectors. The flow rate for the solvent delivery system, model 1100 series degasser, autosampler and pump (Hewlett-Packard), was 0.7 mL/min. The samples were run in triplicate by injecting 200 μL of sample solution and eluting the columns with 50 mM sodium nitrate. The high-performance size-exclusion chromatography (HP-SEC) system included two PL Aquegel OH-60 columns and one OH-40 column (Polymer Laboratories, Amherst, MA) in series set in a water bath at 35°C. The chromatogram was fitted with a Dawn DSP multi-angle laser light scattering photometer (MALLS) (Wyatt Technology, Santa Barbara, CA), model H502 C differential pressure viscometer (DPV) (Visotec, Houston TX), and an Optilab DSP interferometer (RI) (Wyatt Technology). Electronic output from all scattering angles measured by the MALLS, DPV, and RI were sent to a directory of computer for processing with ASTRA software (Wyatt Technology).

Emulsion Stability

The oil-in-water emulsion was prepared by taking 125 mg of Valencia orange oil and an aliquot (208 mL) from 6% corn fiber gum stock solution (12.5 mg CFG) in a 4-mL glass vial and adding enough deionized water to give 2.5 g of total solution. The CFG stock solution was prepared by slowing adding its calculated amount into water containing 0.1% (w/w) sodium benzoate and 0.3% (w/w) citric acid and stirring for overnight for making hydrated and homogeneous solution. No weighing agent was added to avoid the effect of such agents on the emulsification process. The solution to be emulsified was vortexed and then prehomogenized using a polystyrene bench top homogenizer equipped with a 12 mm diameter head (Brinkmann, Switzerland, PT 10/35) at 15,000 rpm for 30 sec. Prehomogenized emulsion was passed through the EmulsiFlex-B3 high-pressure homogenizer (Avestin, Canada) at 10,000 psi homogenization pressure 3x. The resulting emulsion concentration was diluted 31.25 x to 78.125 g in a 10.0% (w/w) sucrose solution containing 0.1% (w/w) sodium benzoate and 0.3% (w/w) citric acid. All emulsions were prepared in triplicate.

The emulsion stability (ES) evaluation was done by turbidity measurement (Pearce and Kimella 1978) with some modification as we explained in Yadav et al (2005b)

\[
T = \frac{2.303 AD}{l}
\]

where T = turbidity in 1/cm, A = observed absorbance at 650 nm, D = dilution factor, and l = path length of the cuvette in cm. The emulsion stability was determined by absorbance (loss of turbidity) measurement of the solution from the middle at 650 nm using a UV-1700 spectrophotometer (Shimadzu, Columbia, MA) against 10.0% sugar solution containing 0.1% sodium benzoate and 0.3% citric acid after 1, 2, and 3 weeks of emulsion preparation.

Particle Size Determination

Emulsion stability was also evaluated by measurement of the volume-weighted average oil-droplet diameter (particle size distribution) in emulsions by Dynamic Light Scattering (DLS), method using a Nicomp 370 submicron particle sizer (Particle Sizing System, Santa Barbara, CA). Correlation functions were measured on light scattered from solutions at an angle of 90°. The instrument parameters were set as follows: control menu-channel width, auto set; liquid viscosity, 0.933 cP; liquid index of refraction, 1.333; intensity set point, 300 kHz; NICOMP input menu-minimum diameter 10 nm; plot size 45; smoothing, 3; plot range, 100. The droplet size distribution was determined after 4 weeks of storage at room temperature by injecting 4 mL of the diluted emulsion.

Confocal Laser Scanning Microscopy

The emulsions were viewed with a model TCS SP confocal laser scanning microscope system integrated with a model IRBE optical microscope fitted with a 63x water immersion lens (Leica Microsystems, Exton PA). Emulsions containing 0.1 (1:10) CFG and oil were prepared and diluted as described above. After standing at room temperature in sealed vials for three months, a 1-mL aliquot from middle of the emulsion bottle was mixed with 5 μL of the hydrophilic dye Nile Red (0.1% in acetonitrile) using a vortex. After standing for 20 min, a 10 μL drop of the dye mixture from each emulsion was placed in a glass bottom microwell dish (MatTek, Ashland, MA) and spread into a thin film by the addition of a dry, clean 10 mm dia. coverslip (degredased by sonication, first in acetonitrile then absolute ethanol). The oil droplets labeled with Nile Red were viewed by excitation of the dye in the sample with the 488 nm laser line of an Argon laser and images of the visible fluorescence were collected at 590–620 nm within single focal planes, each with an estimated thickness of 290 nm, using the LCS software of the microscope system. The size distribution of visible oil droplets in single focal planes was calculated from three digital images of each sample using Fovea Pro 3.0 (Reindeer Graphics, Asheville, NC); images were modified by changing the mode to grayscale, surface flattened, and intensity was inverted before setting the lower and upper threshold limits and measuring selected features.

RESULTS AND DISCUSSION

Extraction of CFG

Coarse and fine corn fiber contained 4 and 14% hexane-extractable materials, respectively, based on the yield of de-oiled corn fiber (Table I). It was essential to remove oil from corn fiber to avoid its oxidation with H 2 O 2 during CFG isolation. The oxidation of fatty acids produces aldehydes, which brings an unpleasant and unwanted smell and aroma in CFG. The starch associated with CF was removed by its digestion into maltodextrins with thermostable α-amylase at 90–95°C, which was essential to avoid alkali-soluble starch contamination of CFG. The yields of de-starched CF from de-oiled coarse and fine fiber were 76.7 and 57.4%, respectively, showing that they contained 23 and 43% starch, and other hot-water-extractable materials. In Yadav et al (2007a), CFG-1 was extracted using the minimum amount of alkali and H 2 O 2 according to the improved isolation procedure of Doner et al (1998) and CFG-2 fraction was obtained from alkali extracted corn fiber residue. The purpose of isolating two fractions was to characterize them separately and study their structure-function relationship. In the present study, the extraction condi-
tion is modified to extract both fractions together. The extraction was accomplished in 0.3M NaOH in presence of 1.26% aqueous H2O2 (1/4 of fiber weight) at boiling temperature for 1 hr and maintaining at pH 11.5 by adding more NaOH. Under these conditions, the amount of alkali was more than 6x higher than the previous isolation (Yadav et al. 2007a) and both alkali and H2O2 were added at the same time for complete solubilization of hemicelluloses. The purpose of adding H2O2 in the alkaline extraction is modified to extract both fractions together. The extraction of active species (.OH and O2.) for delignification process is the pKa for the dissociation of H2O2. At pH 11.5, the concentration of active species (OH and O2.) for delignification process is considered optimum (Gould 1985). In this preparation, CFG (Hemi. B) was extracted with NaOH rather than Ca(OH)2 to increase its yield. The pH of corn fiber solution in saturated Ca(OH)2 is pH 11.4, which drops to about pH 9.8 on addition of H2O2 during extraction. As the optimum pH for the highest delignification of fiber is pH 11.5, at lower pH the delignification becomes extremely slow, affecting the yield of CFG. The yields of CFG obtained from de-oiled and de-starched coarse and fine corn fiber were 39.3 and 23.1%, respectively (Table I), which are slightly higher than the combined yield of CFG-1 and CFG-2 obtained by a mixture of 0.1M NaOH and 0.05M Ca(OH)2 (Yadav et al 2007b). The residue obtained after CFG extraction was suspended in water and stirred for 15 min after adjusting to pH 5.5–6.0. Residue suspended in water was vacuum-filtered and washed with 100% ethanol giving a white powder called cellulose arabinoxylan mixtures (CAX) (Doner and Johnston 2001). The yields of CAX from coarse and fine fiber were 18.5 and 27.0%, respectively (Table I) and they were not investigated further.

**Proximate Composition of CFG**

The proximate analysis data of CFG isolated from coarse and fine corn fiber are given in Table II. The protein content of CFG-C and CFG-F isolated from coarse and fine fiber are 1.14 and 1.97%, respectively. The higher protein content in CFG extracted from the fine fiber than the coarse fiber agrees with our previous report that the endosperm-originating fine fiber contains more protein than the coarse fiber coming from the pericarp portion of corn kernels (Yadav et al 2007c). Moisture content in the CFG from both fiber sources is close (≈6%) but CFG-C contains 2x more ash (≈12%) than the CFG-F (≈6%). The amount of calcium and sodium were determined to make sure they were not present in high amounts that can affect the emulsion stabilities of these CFG samples. A trace amount of calcium (0.007 and 0.032% in CFG-C and CFG-F, respectively) was present but no sodium was detected in any sample.

**Extraction of Protein-Rich Components**

For extraction of protein-rich components, CFG-F was used as it contains more protein than CFG-C. The extraction of CFG-F with 70% ethanol at 60°C for 2 hr produced 19.5% (dry weight basis) soluble fraction containing 6.8% protein (Table III). The protein content in the residue obtained after 70% ethanol extraction reduced from 2% (original CFG-F) to 0.55%, showing that ≥80% of protein went in the soluble fraction. Zein and other hydrophobic protein and peptides are reported to have a maximum solubility in 70% ethanol (Augustine and Baianu 1978; Dickey et al 1998; Parris et al 2002). Thus it appears that this aqueous alcohol soluble fraction is rich in hydrophobic corn protein and peptides.

**Molecular Characterization**

The weight-average molecular weight (Mw), polydispersity index, (Mw/Mn), z-average root mean square radius of gyration (Rg), Mark-Houwink exponent a and the weight average-intrinsic viscosities (ηw) of CFG-F, its 70% Aq. ethanol extract (AEE), and the residue (R), determined by MALLS (multiangle laser light scattering) method is given in Table IV. The weight average molecular weight, Mark-Houwink exponent, and weight average-intrinsic viscosities of R (157, 0.58, and 0.95 respectively) and CFG-F (158, 0.60, and 0.94, respectively) are very close to each other showing similarities in their structures. The lower polydispersity index (1.87) and higher radius of gyration (28.9) of R than CFG-F (2.24 and 25.8, respectively) also indicate that R has homogeneous molecular population but, comparatively, they are not as compact as the molecules in original CFG-F. But the small radius of gyration of CFG-F and R (25.8 and 28.9, respectively) of such high molecules (Mw 157 and 158 kDa, respectively) is a very good indication that, overall, both have very branched and compact structures. The molar mass of AEE (57.5 kDa) is only about one third of the original gum (157 kDa). This lower Mw fraction, which constitutes ≥20% of the total molecules (Table III) has low polydispersity index (1.17), indicating a homogeneous

### Table I

<table>
<thead>
<tr>
<th>Percentage Yieldsa of De-oiled and De-starched Corn Fiber and Its Constituents</th>
<th>Total of CFG and CAX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>De-oiled and De-starched</strong></td>
<td><strong>CF</strong></td>
</tr>
<tr>
<td><strong>Coarse CF</strong></td>
<td>96.4</td>
</tr>
<tr>
<td><strong>Fine CF</strong></td>
<td>85.6</td>
</tr>
</tbody>
</table>

| a Based on the amount of dry corn fiber. |
| b Based on the amount of de-oiled corn fiber. |
| c Based on the amount of de-oiled and de-starched corn fiber. |
| d CFG also called Hemi. B. |

### Table II

<table>
<thead>
<tr>
<th>Proximate Composition of CFG Samplesa</th>
<th>Protein Contentb</th>
<th>Moisture</th>
<th>Ash</th>
<th>Na</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFG-C</td>
<td>1.14 ± 0.04</td>
<td>5.84</td>
<td>11.95</td>
<td>ndc</td>
<td>0.007</td>
</tr>
<tr>
<td>CFG-F</td>
<td>1.97 ± 0.01</td>
<td>6.32</td>
<td>6.05</td>
<td>nd</td>
<td>0.032</td>
</tr>
</tbody>
</table>

| a CFG isolated from coarse (C) and fine (F) corn fiber. Data are average of three runs ± SD. |
| b Wt% based on dry weight of CFG samples. |
| c Not detected. |

### Table III

<table>
<thead>
<tr>
<th>CFG-F Fractions and Acacia Gums (Protein Contents)a</th>
<th>% Yield (w/w)</th>
<th>Protein Wt%.b</th>
</tr>
</thead>
<tbody>
<tr>
<td>R from 70% AEE</td>
<td>66.0</td>
<td>0.55 ± 0.03</td>
</tr>
<tr>
<td>70% AEE</td>
<td>19.5</td>
<td>6.81 ± 0.12</td>
</tr>
<tr>
<td>Commercial gum samples</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAG</td>
<td>na</td>
<td>0.44 ± 0.00</td>
</tr>
<tr>
<td>MAG</td>
<td>na</td>
<td>1.75 ± 0.00</td>
</tr>
</tbody>
</table>

| a CFG-F, corn fiber gum, fine; R, residue; AEE, aqueous ethanol extract; NAG, native acacia gum; MAG, modified acacia gum. |
| b Wt% of proteins is average of three runs ± SD. |
| c Not applicable.
population. Though it has lower radius of gyration (18.7), its Mark-Houwink exponent (0.80) is high in comparison to the bigger molecules CFG-F and R (0.58 and 0.60, respectively).

This clearly shows that this low Mw fraction is less branched but occupies more space per molar mass giving a less compact structure than R and the unfractionated CFG-F. The weight average-intrinsic viscosities (η_w) of all samples correlate well with Mw, showing that the higher Mw fraction is more viscous than the lower one.

**Emulsion Stability**

The emulsion stability of CFG-F, the residue (R) obtained from its 70% aqueous ethanol extraction and protein-rich 70% aqueous ethanol extract (AEE) of CFG-F were determined in oil-in-water emulsion system and compared with modified acacia gum (MAG) and native acacia gum (NAG), which are standard well-known emulsifiers. Figure 1 shows the emulsion stability (turbidity) of these samples studied after storage at room temperature for 1, 2, and 3 weeks. The sample without any emulsifier is labeled as control. The emulsifying efficiency of these samples has been investigated through the formulation of 5% orange oil in water emulsions at pH 3.2 with 10:1 oil to gum ratio by taking an aliquot from the middle of the diluted emulsion after 1, 2, and 3 weeks. As shown in Fig. 1, the emulsion stability of protein-depleted R is lower than the whole CFG-F during all three weeks of the study. This would appear to show the importance of protein-rich component in the emulsification process. However, the emulsion stabilizing ability of the protein-rich AEE is not better than R, but is slightly worse. Neither fraction is as effective as the unfractionated CFG-F. Thus it clearly demonstrates that the whole CFG-F in its original form is a better emulsifier than its fractionated components. It also indicates that the hydrophobic protein component is important for emulsion stability in the beverage emulsion systems, if it is linked or associated with a high molecular weight hydrophilic carbohydrate polymer.

The emulsion stability was also assessed by droplet-size measurement using a dynamic light scattering (DLS) method. Figure 2 shows that the volume weighted average oil-droplet size in emulsions of whole CFG-F is smaller than its residue (R) obtained after 70% aqueous ethanol extraction that removes hydrophobic protein-rich components. However, the droplet size in the hydrophobic protein-enriched AEE fraction was indeterminate due to droplets density below detection level, showing unstable emulsion.

The emulsion stability test was performed also by CLSM after three months of storage at room temperature. CLSM observation shows that the average particle size of emulsions prepared with the unfractionated CFG-F is comparatively smaller than the emulsions made with either aqueous ethanol extracted CFG residue R or the extract AEE (Table V). The particle size of CFG-F emulsions is very close to the particles size of well known commercial emulsifiers MAG and NAG. The number of particles (oil droplets) per total image area observed in CFG-F emulsions is also greater than the emulsions made with R and AEE, but less than MAG and close to NAG. The droplet distribution in CFG-F, R and AEE stabilized emulsions observed by CLSM show that CFG-F containing emulsions (Fig. 3A) have higher droplets density than emulsions prepared with R and AEE (Fig. 3B and C). But the droplets density in emulsions prepared with R is higher than AEE-containing emulsions, suggesting that aqueous ethanol extracted residue of CFG-F is a better emulsifier than its protein-rich extract.

All these results clearly indicate that though the aqueous ethanol extract of CFG-F is rich in protein, it does not make a very stable emulsion after four weeks of storage at room temperature (particle size analysis, Fig. 2) and as good emulsion as CFG-F (turbidometric and CLSM analyses; Fig. 1 and Table V, respectively). Thus, it appears that the amount of protein is not as important as the type of protein associated with polysaccharides for emulsion stability. The association of hydrophobic protein with a high molecular weight polysaccharide is important for good emulsion stabilizing capacity. The whole CFG-F was capable of producing emulsion droplets similar to modified acacia gum (MAG) and smaller droplets than a native acacia gum (NAG). Thus, the emulsion stability of CFG-F is as good as MAG, which was pre-

---

**TABLE IV**

<table>
<thead>
<tr>
<th>Sample</th>
<th>M_w x 10^3</th>
<th>M_w/M_n</th>
<th>R_g (nm)</th>
<th>α</th>
<th>η_w</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFG-F</td>
<td>157 ± 6</td>
<td>2.24 ± 0.3</td>
<td>25.8 ± 2</td>
<td>0.58 ± 0.03</td>
<td>0.95 ± 0.04</td>
</tr>
<tr>
<td>R</td>
<td>158 ± 0.6</td>
<td>1.87 ± 0.06</td>
<td>28.9 ± 2</td>
<td>0.60 ± 0.01</td>
<td>0.94 ± 0.03</td>
</tr>
<tr>
<td>AEE</td>
<td>57.5 ± 1</td>
<td>2.09 ± 0.01</td>
<td>18.7 ± 1</td>
<td>0.80 ± 0.05</td>
<td>0.76 ± 0.08</td>
</tr>
</tbody>
</table>

* Determined by multiangle light-scattering method. CFG-F, corn fiber gum, fine; R, residue; AEE, aqueous ethanol extract.
Fig. 3. Sections of confocal micrographs of emulsions with 0.1 gum-to-oil ratio (w/w) stabilized by CFG-F and its fractions after storage at room temperature for three months. A–C: CFG-F, R, and AEE, respectively. Scale bar = 31.75 μm. All images are at the same scale and magnification.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of Particles/Total Image Area</th>
<th>Avg. Particle Size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFG-F</td>
<td>72 ± 9</td>
<td>1.026 ± 0.47</td>
</tr>
<tr>
<td>R</td>
<td>60 ± 14</td>
<td>1.193 ± 0.109</td>
</tr>
<tr>
<td>AEE</td>
<td>34 ± 3</td>
<td>1.354 ± 0.197</td>
</tr>
<tr>
<td>MAG</td>
<td>107 ± 6</td>
<td>1.065 ± 0.137</td>
</tr>
<tr>
<td>NAG</td>
<td>76 ± 7</td>
<td>1.103 ± 0.126</td>
</tr>
</tbody>
</table>

a CFG-F, corn fiber gum, fine; R, residue; AEE, aqueous ethanol extract; NAG, native acacia gum; MAG, modified acacia gum. Average from three images ± SD.

tested by the supplier as a better emulsifier than NAG. This also supports our previous finding that CFG can be a gum arabic replacement for the beverage emulsion systems (Yadav et al 2007a).

The importance of protein in the emulsification process is well studied by several research groups. The role of proteinaceous components of gum arabic in the emulsification process is well documented (Garti 1999). The enhancement of emulsion stability by the functional properties of maltodextrin on conjugation with whey protein and β-lactoglobulin has been described (Dickinson et al 1995; Akhtar and Dickinson 2007).

CONCLUSIONS

Our study suggests that all of the proteinaceous components are not integral components of CFG and can be extracted with a moderately nonpolar aqueous alcohol. The level of protein in CFG-F can be reduced from 2% to ≤0.6% but all protein cannot be removed, showing that some proteins are still strongly associated or covalently bound. When hydrophobic protein components are extracted from CFG-F, it loses some, but not all, of its emulsifying efficiency. This indicates that, in addition to hydrophobic protein, a typical high molecular weight branched and compact structure of CFG-F is important for emulsifying properties. Though AEE is rich in hydrophobic protein components, the Mw is low and it lacks a highly branched and compact structure, making it a less effective emulsifier. Thus it seems that the combination of hydrophobic protein-rich components and other molecular species present in CFG-F make it an excellent emulsifier for a beverage emulsion system.

ACKNOWLEDGMENTS

We are pleased to acknowledge Charles Onwulata for permission to use the particle size measurement facility; Hoo K. Chau, Stefanie Simon, and Audrey Thomas for technical assistance; Michael Kurantz for the protein, moisture, ash, Ca, and Na determination; Paul Pierlott for arranging the microscopic images for the manuscript; and Kyle Beery from ADM Research for providing corn fiber samples.

LITERATURE CITED


