

# Molecular Characteristics of Corn Fiber Gum and Their Influence on CFG Emulsifying Properties

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## ABSTRACT

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The molecular characteristics of two purified arabinoxylan fractions derived from corn kernels, corn fiber gum-1 and -2 (CFG-1 and -2), have been studied and correlated with emulsifying properties. CFG-1 and -2 fractions were isolated from different corn fiber sources by 1) a sequential alkaline extraction and H<sub>2</sub>O<sub>2</sub> bleaching to produce CFG-1; and 2) additional H<sub>2</sub>O<sub>2</sub> treatment of the alkali-extracted residue at pH 11.5, yielding CFG-2. Multiangle laser light-scattering and online viscosity were used to measure the molar mass, polydispersity, structure compactness, and intrinsic viscosity of the generated CFG fractions. Emulsification prop-

erties in an oil-in-water emulsion system with 10:1 oil-to-gum ratio was investigated by measuring turbidity of an aliquot from the bottom of the diluted emulsion over 10 days. The isolated CFG-2 from each fiber source was higher in weight-average molar mass ( $M_w$ ) polydispersity ( $M_w/M_n$ ) and structure compactness, and also lower in solution weight-average intrinsic viscosity ( $\eta_w$ ) than the corresponding CFG-1. Average  $M_w$  and  $\eta_w$  values were 244–491 kDa and 1.35–1.84 dL/g, respectively. The emulsion stabilizing capacity of CFG-2 from each fiber source was superior to the corresponding CFG-1.

Corn fiber arabinoxylan is a hemicellulose B isolated from the fibrous portions (pericarp, tip cap, and endosperm cell wall fractions) of corn kernels and is commonly referred to as corn fiber gum (CFG). Previously (Yadav et al 2007a), we reported CFG as a potential gum arabic replacer to stabilize flavor oil emulsions in water that are used by the soft drink industry (Verbeken et al 2003). But the precise mechanism for the stabilization of oil-in-water emulsion is not well understood due to its structural and molecular complexity. It appears that CFG is a unique polysaccharide with excellent emulsifying properties and a low solution viscosity. Such behavior could be due to molecular characteristics that are not general characteristics of all polysaccharides. Study of the structure of the isolated and purified gum has indicated that it consists of a highly branched  $\beta$ -1–4-linked xylopyranose backbone with  $\alpha$ -L-arabinofuranose residues as side chains on both primary and secondary hydroxyl groups (Saulnier et al 1995). The polysaccharide also contains small amounts of other neutral sugars and glucuronic acid. Purified CFG contains a small amount of protein (0.5–5% depending on the fiber source and isolation method) which may play an important role in its surface properties at the oil-water interface in the emulsion system (Yadav et al 2006, 2007a). Properties of polysaccharide gums in water are greatly affected by the molecular characteristics of the gum molecule.

For long-term emulsion stability of small oil droplets in an aqueous phase, the molecular characteristics of the adsorbed biopolymer should be such that it can produce a molecular barrier at the oil-water interface. Molecular weights and degree of branching of arabinoxylans have a great effect on their physical properties (Ebringerova et al 1999).

Our previous studies (Yadav et al 2006, 2007a) indicated that the corn fiber source used for CFG isolation had an effect on its chemical composition and emulsifying properties. There are currently two main commercial sources for corn fiber: the corn wet-milling and dry-milling industries. Wet milling of corn produces two different types of fiber fractions: a “coarse” fiber from the kernel’s pericarp and tip cap, and a “fine” fiber derived from the

kernel’s endosperm. Normally, both these fractions are combined and used to prepare animal feeds. Dry-milling produces a bran fraction that is primarily composed of pericarp fiber only. Fishman et al (2000) previously reported the physical characteristics of CFG isolated by different ratios of NaOH and Ca(OH)<sub>2</sub>. In that study, the CFG was isolated from a mixture of wet-milled pericarp and endosperm fiber. The present investigation was undertaken for detailed molecular characterization of purified CFG-1 and -2 samples isolated from each of the commercial sources, including wet-milling pericarp fiber, wet-milling endosperm fiber, dry-milling pericarp fiber, and a mixture of wet-milling pericarp and endosperm fiber. Another goal was to search for correlations between the molecular structure of the different CFG-1 and -2 samples and their emulsion stabilizing capacity. In this report, we describe for the first time, the emulsifying properties of CFG isolated from wet-milling pericarp fiber and from wet-milling endosperm fiber. A third goal was to determine which sources of corn fiber are best for producing the CFG with desirable functional properties. CFG-1 and -2 fractions were isolated separately by 1) alkaline extraction and H<sub>2</sub>O<sub>2</sub> bleaching, and 2) alkaline H<sub>2</sub>O<sub>2</sub> treatment of prior alkali-treated residue respectively, to obtain a better understanding of their structure/function relationship.

## MATERIALS AND METHODS

### Materials

Corn fiber samples were kindly provided by ADM Research, Bunge (North America, Bunge Milling, St. Louis, MO) and Cargill Central Research (Minneapolis, MN). They were oven-dried by the suppliers before shipping. Fiber samples were ground to a 20-mesh particle size using a Wiley mill and extracted with hexane to remove oil (Moreau et al 1996). Starch was removed from the 20-mesh deoiled fiber by treating with Termamyl  $\alpha$ -amylase (Novozymes, Davis, CA) (Doner et al 1998; Doner and Johnston 2001). Cold-pressed Valencia orange oil was a gift from Citrus and Allied Essence (Belcamp, MD).

### Corn Fiber Gum (CFG) Isolation

CFGs were isolated from deoiled and destarched corn fiber according to the alkaline H<sub>2</sub>O<sub>2</sub> procedures of Yadav et al (2006, 2007a). In brief, deoiled and destarched corn fiber was mechanically stirred into an alkaline solution (pH 11.5) containing 1 meq each of NaOH and Ca(OH)<sub>2</sub> per gram of fiber in the extraction medium and boiled for 1 hr. The residue obtained after centrifugation was resuspended in water, boiled for 5 min, and centrifuged again. The combined supernatant was treated with

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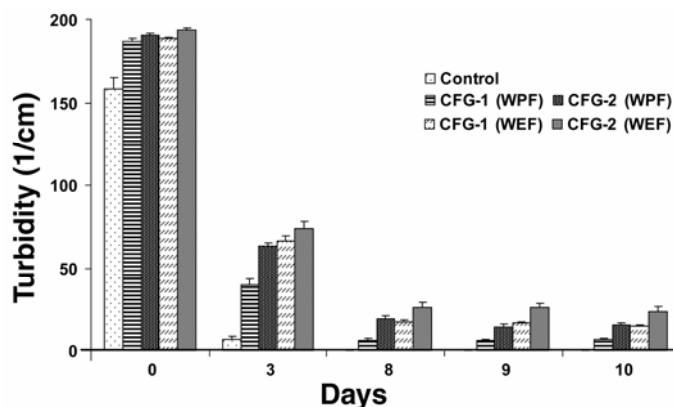
H<sub>2</sub>O<sub>2</sub> at pH 11.5 for 2 hr and then adjusted to pH 4.0–4.5 to precipitate Hemicellulose A. The supernatant was treated with two volumes of ethanol to precipitate Hemicellulose B (CFG-1). The precipitate was collected and dried in a vacuum oven. The residue left after alkali extraction was further extracted with alkaline H<sub>2</sub>O<sub>2</sub> (0.1g/g of fiber, pH 11) at a boiling temperature for 1.5 hr. The residue was removed by centrifugation and the supernatant was adjusted to pH 4.0–4.5 to precipitate Hemicellulose A. The CFG-2 was obtained from the supernatant by precipitating with 2 volumes of ethanol, collecting the precipitate, and drying it in a vacuum oven as above.

### Emulsion Preparation

The oil-in-water emulsions were prepared by taking 125 mg of Valencia orange oil and 208 mg of solution from a 6% CFG stock solution in a 4-mL glass vial and adding enough deionized water to give 2.5 g of total solution. The 6% CFG stock solution was prepared by adding the required amount of gum into water containing 0.1% (w/w) sodium benzoate and 0.3% (w/w) citric acid and stirring overnight to prepare a hydrated and homogeneous solution. No weighting agents were added to avoid the effects of such agents on the emulsification process. The solution to be emulsified was vortexed and then prehomogenized using a polytron bench-top homogenizer equipped with a 12 mm diameter head (Brinkmann, Switzerland, PT 10/35) at 15,000 rpm for 30 sec. The prehomogenized emulsion was passed through the EmulsiFlex-B3 high-pressure homogenizer (Avestin, Canada) 3× at 10,000 psi homogenization pressure. The resulting emulsion concentrate was diluted 31.25× 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.

### Evaluation of Emulsion Stability

The emulsion stability (ES) evaluation was done by turbidity measurements (Pearce and Kinsella 1978) with some modification as previously explained (Yadav et al 2007a).  $T = 2.303AD/l$ , where  $T$  = turbidity in 1/cm,  $A$  = 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 bottom of the bottle at 650 nm using a UV-1700 spectrophotometer (Shimadzu, Columbia, MA) in comparison with a 10.0% sugar solution containing 0.1% sodium benzoate and 0.3% citric acid at 0, 3, 8, 9, and 10 days after emulsion preparation.



**Fig. 1.** Emulsion stability (turbidity) of corn fiber gum (CFG-1 and -2) from wet-milling pericarp fiber (WPF) and from wet-milling endosperm fiber (WEF) at room temperature after 0, 3, 8, 9, and 10 days. Turbidity was measured by taking an aliquot from the bottom of the bottle containing a diluted emulsion. Higher turbidity is an indication of higher emulsion stability. Data are an average of three trials  $\pm$  standard deviation.

### Sample Preparation for Chromatography

A solution of 2 mg/mL of CFG was prepared by slowly adding 20 mg of gum sample with vigorous stirring into 10 mL of 50 mM NaNO<sub>3</sub> solution (mobile phase for chromatography) at room temperature to make a homogeneous solution. The gum solution was dialyzed against 1L of 50 mM NaNO<sub>3</sub> (the outside solution was changed 4×) using 6–8,000 MW cut-off dialysis tubing. The dialyzed solution was centrifuged at 50,000  $\times$   $g$  for 10 min at 35°C and filtered through a 0.22- $\mu$ m sterile Millex-HV filter (Millipore Corp., Bedford, MA).

### Chromatography

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  $\mu$ L of sample solution and eluting the columns with 50 mM sodium nitrate. The high-performance size-exclusion chromatography (HPSEC) system comprised two PL Aquagel OH-60 columns and one OH-40 column (Polymer Laboratories, Amherst, MA) in series set in a water bath at 35°C. The chromatograph was fitted with a Dawn DSP multiangle laser light-scattering photometer (MALLS) (Wyatt Technology, Santa Barbara, CA), model H502 C differential pressure viscometer (DPV) (Viscotek, Houston TX), and an Optilab DSP interferometer (RI) (Wyatt Technology). Electronic outputs from the 90°C light-scattering, DPV, and RI were sent to one directory of a computer for processing with TRISEC software (Viscotek). Electronic output from all the scattering angles measured by the MALLS, DPV, and RI was sent to a second directory for processing with ASTRA software (Wyatt Technology).

## RESULTS AND DISCUSSION

From the oil- and starch-free fiber, most of the CFG was isolated by a mixture of 0.1M NaOH and 0.05M Ca(OH)<sub>2</sub> (mild alkali mixture, pH 11.5) and bleached with 0.1 g of H<sub>2</sub>O<sub>2</sub>/g of fiber (Doner et al 1998). This mild alkali-extracted arabinoxylan was named CFG-1. The mild alkali-extracted residue was further extracted with alkaline H<sub>2</sub>O<sub>2</sub> (0.1g/g of fiber, pH 11.5) to isolate the mild alkali-resistant arabinoxylan and was named CFG-2 (Yadav et al 2006, 2007a). The CFG-1 fraction most likely was linked to the insoluble cell wall polymeric matrix by phenolic and nonphenolic ester linkages. The mild alkali-resistant CFG-2 fraction was more strongly associated with the cell wall matrix, and was extractable only with alkaline H<sub>2</sub>O<sub>2</sub> after the CF matrix became more accessible to extraction due to prior alkali treatment. The strong association of CFG-2 to the cell wall may be due to a higher molecular weight with more branching or to its being connected to the matrix by alkali-resistant ether linkages.

The capacity to stabilize orange oil emulsion in water by CFG-1 and -2 isolated from wet milling pericarp fiber (WPF) and from wet milling endosperm fiber (WEF) was studied. The efficiency of emulsification was determined from turbidity measurements after 0, 3, 8, 9, and 10 days. The higher turbidity indicates a better emulsion stability. Turbidity of an emulsion is directly proportional to optical density, which increases as droplet size decreases (Randall et al 1989). Thus, a superior emulsion is indicated by a higher optical density or turbidity. Figure 1 shows the stabilities of oil-in-water emulsion in the absence of any emulsifier (control) and in the presence of four CFG emulsifiers. The double homogenization, first using a polytron homogenizer and then a high-pressure homogenizer produced such a homogeneous emulsion that at zero time all CFG samples showed a similar turbidity. The turbidity of all emulsions dropped from  $>175$  cm<sup>-1</sup> to  $<75$  cm<sup>-1</sup> in three days but was stable at  $<25$  cm<sup>-1</sup> after eight days. It is noteworthy that the emulsion stabilities of CFG-2 from both WPF and WEF were superior to the corresponding CFG-1 fraction.

After three days, turbidity of all samples decreased, but the turbidity of the CFG-2 fraction stayed higher than the corresponding CFG-1 fraction isolated from the same fiber source during the whole experiment time. After eight days, there was no emulsion breakage and so the particle size stayed the same, giving the same turbidity reading on the ninth and tenth days. Thus, it is very clear from Fig. 1 that the surface activities of the CFG-2 fraction are better than the corresponding CFG-1 fraction. Previously we reported that the long-term oil-in-water emulsion stabilizing capacities of CFG-2 isolated from a mixture of wet-milling pericarp and endosperm fiber (WPEF) and dry-milling pericarp fiber (DPF) were superior to the corresponding CFG-1 (Yadav et al 2006, 2007a). The superior emulsion stabilizing capacities of CFG-2 to corresponding CFG-1 might be associated with higher  $M_w$  and degree of branching in addition to higher protein content (Table I).

A good correlation between emulsion stability and average  $M_w$  of a well-known emulsifier was observed by Dickinson et al (1991a) for gum arabic. They reported that the 10% population of gum arabic separated by gel-permeation chromatography had the highest molecular weight and  $\approx 0.38\%$  nitrogen content, but it produced a more stable emulsion than the remaining 90% gum arabic population which had about the same nitrogen content (0.35%) but lower molecular weight. A similar correlation was observed when the average molecular mass of a gum arabic sample with  $\approx 0.35\%$  nitrogen content was degraded from  $310 \times 10^3$  to  $220 \times 10^3$  by irradiation, in that its emulsion stabilizing capacity was reduced significantly (Dickinson et al 1991b). Most recently, exactly the same correlation was observed by Aoki et al 2007, when they prepared a series of *Acacia senegal* test gums including a new commercial product *Acacia* (sen) Super Gum EM2 from a commercial *Acacia senegal* product by a controlled maturation process. They reported that commercial gum arabic weight-average  $M_w \approx 6 \times 10^5$  Da did not produce a stable emulsion at concentrations  $< 20\%$ . But when the weight-average  $M_w$  was increased to a range of  $1-2.5 \times 10^6$  Da by a controlled maturation process, the emulsion stability was greatly increased under a similar condition, even at a 5% gum concentration. The likely explanation for this is that absorption of high molecular mass polymers on the surface of oil droplets forms a thick and highly effective long-term steric stability on emulsions by preventing the tiny oil droplets from coalescing.

The weight-average  $M_w$ , polydispersity, ( $M_w/M_n$ ), and z-average root-mean-square radius of gyration ( $R_{gz}$ ) of CFG-1 and -2 from WPF, WEF, WPEF, and DPF were determined using two methods (MALLS and LSV) as shown in Table I. The protein content in those samples as reported previously (Yadav et al 2007a,b) are also shown in Table I. The  $M_w$  of these CFGs varies from 244 to 491 kDa, which lies in the range of the reported molecular weights

of CFG extracted from different fiber sources under different alkaline conditions (Saulnier et al 1995; Doner et al 1998; Fishman et al 2000). The molar masses obtained by both methods show that the CFG-2 has a higher  $M_w$  and a higher  $M_w/M_n$  than the corresponding CFG-1 from each respective source. The higher  $M_w/M_n$  index of CFG-2 than CFG-1 from all fiber sources indicates that CFG-2 contains a higher ratio of high molecular weight polymers than CFG-1. The molar mass discrepancies between the MALLS and LSV methods was  $\approx 8-20\%$ . Fishman et al (2000) reported 1.3–20% in a previous report.  $M_w$  values for all samples measured by MALLS method was higher (8–20%) than by LSV method. The higher  $M_w$  and  $M_w/M_n$  of CFG-2 than CFG-1 agree with the reported  $M_w$  and  $M_w/M_n$  for  $S_2$  and  $S_1$  hemicellulose fractions from maize bran extracted sequentially with 0.5M NaOH and 1.5M KOH (Saulnier et al 1995). The radii of gyration ( $R_{gz}$ ) values for CFG-2 from all fiber sources measured by LSV method are slightly higher than those of CFG-1. But  $R_{gz}$  values obtained by MALLS method for both CFG-1 and -2 are very close to each other. So, in this case, no solid conclusions can be drawn. If we rely more on the LSV method, CFG-2 from all fiber sources have higher  $R_{gz}$  than the corresponding CFG-1.

The Mark-Houwink exponent  $a$  values measured by both the MALLS and LSV methods were slightly lower for CFG-2 than for the corresponding CFG-1 from all fiber sources (Table II). The lower  $a$  value is an indication of a more compact structure. So it looks obvious that although CFG-2 have a higher  $M_w$ , they are somewhat more compact than the corresponding CFG-1. Many investigators reported that corn kernel arabinoxylan fractions (CFG) were highly branched (Whistler et al 1955, 1956; Montgomery et al 1957; Saulnier et al 1995). Thus it can be interpreted that high  $M_w$  branched polymers were well aggregated and occupied less space per molar mass unit to give a more compact structure than the comparatively partially dissociated lower  $M_w$  polymer. The Mark-Houwink exponent  $a$  values measured by both methods were close to each other; however, the LSV method consistently gave slightly higher values for all samples than the MALLS method. It appears that CFG with higher  $M_w$  were more compact and strongly associated with the cell wall matrix. Those molecules were liberated from the cell wall matrix by alkaline  $H_2O_2$  treatment only after prior treatment of CF with alkali to make the cell wall matrix more accessible to extraction in addition to breaking other alkali-resistant linkages.

The weight-average intrinsic viscosities ( $\eta_w$ ) of CFG samples determined by both MALLS and LCV methods were 1.35–1.84 dL/g (Table II), which are close to the values (1.59–1.81 dL/g) for  $S_1$  and  $S_2$  corn hemicellulose fractions, respectively, reported by Saulnier et al (1995).

TABLE I  
Molar Mass ( $M_w$ ), Polydispersity ( $M_w/M_n$ ), and Radius of Gyration ( $R_{gz}$ ) of Corn Fiber Gum Fractions (CFG-1 and -2)

Samples	$M_w \times 10^3$		$M_w/M_n$	$R_{gz}$ (nm)		Protein Content
	MALLS <sup>a</sup>	LSV <sup>b</sup>	MALLS	MALLS	LSV	
WPF						
CFG-1	338 ± 6	277 ± 2	1.56 ± 0.01	35.4 ± 0.1	27.5 ± 0.3	1.90 <sup>c</sup>
CFG-2	426 ± 4	391 ± 3	2.05 ± 0.03	34.1 ± 0.1	31.4 ± 0.06	2.88 <sup>c</sup>
WEF						
CFG-1	296 ± 5	258 ± 1	1.74 ± 0.01	35.7 ± 0.3	29.4 ± 0.2	4.64 <sup>d</sup>
CFG-2	359 ± 6	332 ± 2	1.87 ± 0.03	35.3 ± 0.7	31.2 ± 0.3	5.14 <sup>d</sup>
DPF						
CFG-1	290 ± 4	244 ± 6	1.35 ± 0.01	29.5 ± 0.3	24.0 ± 0.2	0.44 <sup>c</sup>
CFG-2	491 ± 11	452 ± 5	1.86 ± 0.01	32.6 ± 0.2	31.6 ± 0.5	0.94 <sup>c</sup>
WPEF						
CFG-1	334 ± 5	292 ± 5	1.49 ± 0.02	35.4 ± 0.5	28.8 ± 0.5	1.31 <sup>c</sup>
CFG-2	452 ± 12	416 ± 8	1.95 ± 0.03	34.5 ± 0.1	32.4 ± 0.9	3.75 <sup>c</sup>

<sup>a</sup> Multiangle light-scattering method.

<sup>b</sup> Combination of light-scattering at 90° and viscometry method.

<sup>c</sup> Obtained from Yadav et al (2007a).

<sup>d</sup> Obtained from Yadav et al (2007b).

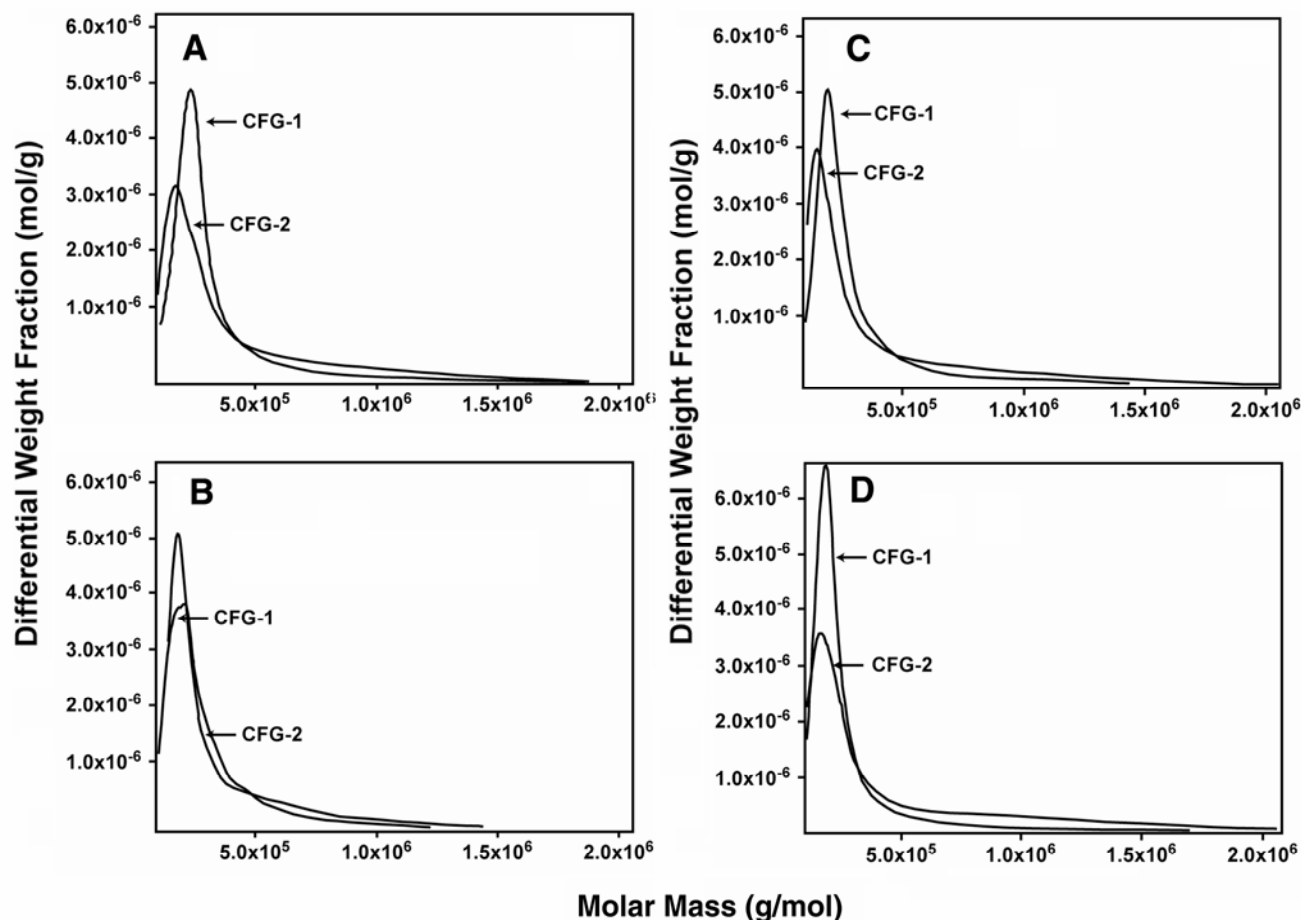


Fig. 2. Differential molar mass curves of corn fiber gum (CFG) 1 and -2 isolated from wet-milling pericarp fiber (WPF) (A); wet-milling endosperm fiber (WEF) (B); wet-milling pericarp and endosperm fiber (WPEF) (C); and dry-milling pericarp fiber (DPF) (D).

TABLE II  
Mark-Houwink Exponent ( $a$ ) and Intrinsic Viscosity ( $\eta_w$ ) of Corn Fiber Gum Fractions (CFG-1 and -2)

Samples	$a$		$\eta_w$	
	MALLS <sup>a</sup>	LSV <sup>b</sup>	MALLS	LSV
WPF				
CFG-1	0.59 ± 0.02	0.62 ± 0.02	1.49 ± 0.02	1.60 ± 0.06
CFG-2	0.43 ± 0.01	0.47 ± 0.01	1.43 ± 0.03	1.48 ± 0.01
WEF				
CFG-1	0.64 ± 0.03	0.68 ± 0.02	1.71 ± 0.030	1.84 ± 0.01
CFG-2	0.47 ± 0.4	0.51 ± 0.01	1.62 ± 0.03	1.74 ± 0.03
DPF				
CFG-1	0.53 ± 0.02	0.56 ± 0.02	1.35 ± 0.02	1.38 ± 0.03
CFG-2	0.36 ± 0.01	0.37 ± 0.004	1.40 ± 0.02	1.43 ± 0.05
WPEF				
CFG-1	0.59 ± 0.02	0.63 ± 0.01	1.69 ± 0.04	1.74 ± 0.01
CFG-2	0.42 ± 0.01	0.44 ± 0.01	1.62 ± 0.05	1.61 ± 0.04

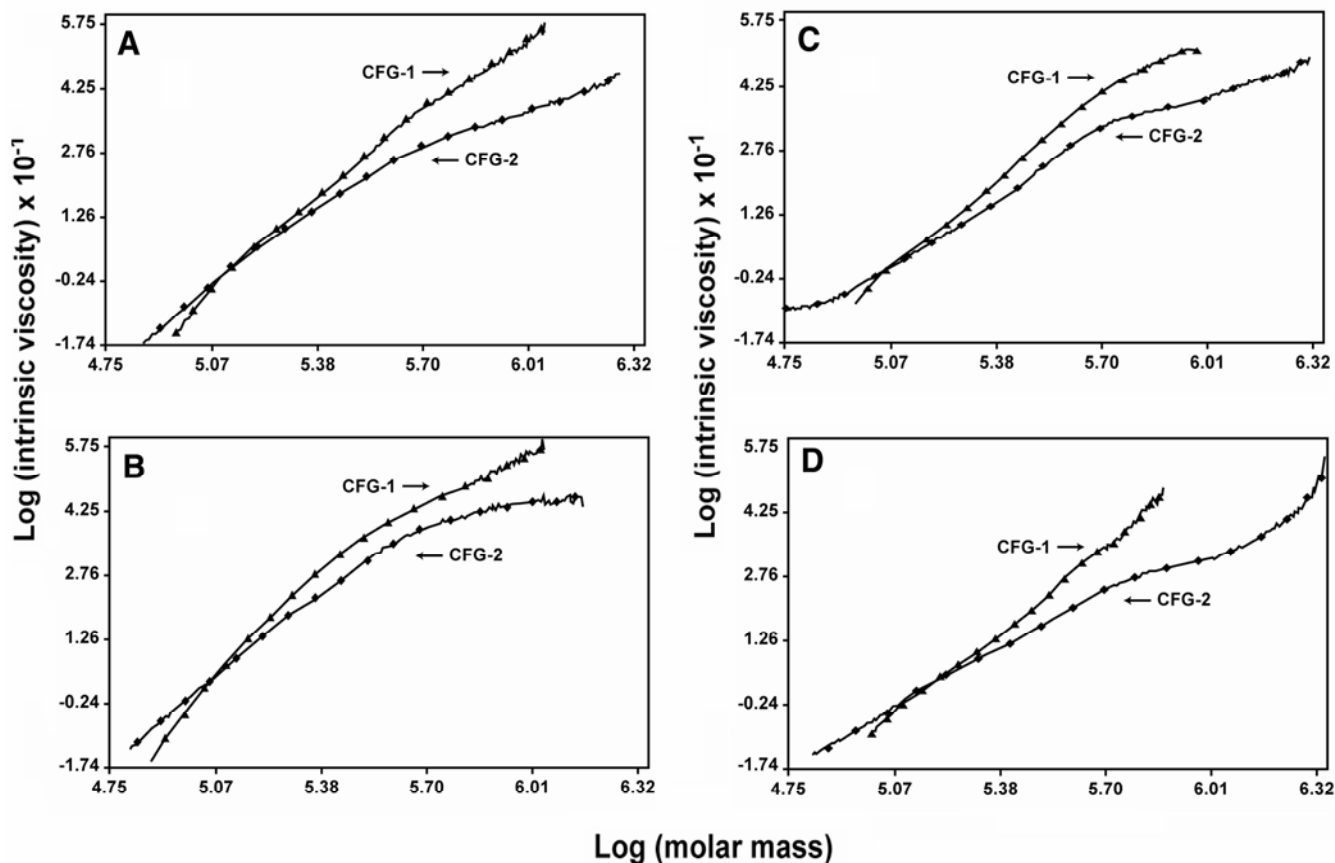
<sup>a</sup> Multiangle light-scattering method.

<sup>b</sup> Combination of light-scattering at 90° and viscometry method.

CFG-1 from each fiber source is slightly more viscous than the corresponding CFG-2, except CFG from dry-milling pericarp fiber in which the  $\eta_w$  are very close to each other. Although the  $M_w$  of CFG-1 is lower, the intrinsic viscosities from three fiber sources are slightly higher than the corresponding CFG-2. This  $\eta_w$  result contradicts previous reports (Saulnier et al 1955; Fishman et al 2000) that showed that the higher  $M_w$  fraction was slightly more viscous than the lower  $M_w$  fraction. Nevertheless, the difference in  $\eta_w$  values for both CFG fractions is very small, which can easily occur due to differences in the extraction conditions of hemicelluloses. There is a possibility that, as with pectin (Kravtchenko et al 1992), some high  $M_w$  CFG are fragmented and reaggregated to

give the same high  $M_w$  polymers but with reduced viscosity of the gum solution. Such polymers of high  $M_w$  with low viscosity are desired by food industries for many practical applications.

Figure 2 shows the differential weight fraction (mol/g) plotted against molar mass for CFG-1 and -2 from WPF, PEF, WPEF, and DPF. The superimposed differential molar mass curves for CFG from all four fiber sources show that CFG-2 from each source contains higher population of high  $M_w$  fractions (also indicated by higher  $M_w/M_n$  values) (Table I) than the corresponding CFG-1 from the same fiber source. The molar mass curve for CFG-1 from each source is narrower and taller than CFG-2, but it contains more low  $M_w$  fractions. This clearly indicates that CFG-2 isolated



**Fig. 3.** Mark-Houwink plots for CFG-1 and -2 isolated from wet-milling pericarp fiber (WPF) (A); wet-milling endosperm fiber (WEP) (B); wet-milling pericarp and endosperm fiber (WPEF) (C); and dry-milling pericarp fiber (DPF) (D).

from alkali-treated corn fiber by alkaline  $H_2O_2$  had a higher proportion of branched and high  $M_w$  fractions. Mark-Houwink plots for CFG-1 and -2 from four fiber sources (WPF, WEP, WPEF, and DPF) are shown in Fig. 3 (Mark-Houwink exponents are given in Table II). All plots show the bimodal nature of CFG distribution as previously reported for hemicelluloses from corn fiber (Fishman et al 2000). The log intrinsic viscosity values of all gum samples increase with the increasing log molar masses. Each CFG-2 shows comparatively lower viscosity than the corresponding CFG-1, which is a good indication that CFG-2 are more branched (highly substituted) than the CFG-1. This result agrees with the findings of Garti et al (1997) that more-substituted galactomannan from fenugreek was less viscous than less-substituted galactomannan from guar gum. Such a property is considered to be useful for making a gum a unique emulsifier for use in oil-in-water beverage emulsion systems. For producing oil-in-water emulsion systems, an emulsifier with high solubility and low viscosity is considered to be the most useful.

### CONCLUSIONS

The present investigation has shown that CFG-2 is strongly associated with the cell wall matrix, which becomes extractable with more concentrated alkali in the presence of  $H_2O_2$ . CFG-2 from all corn fiber sources contains a higher ratio of high molecular weight polymers and is more compact and less viscous than the corresponding CFG-1.

The result presented in this report clearly supports the idea that the higher  $M_w$  CFG-2 fraction from all corn fiber sources is a more effective emulsifier for oil-in-water emulsion systems than the corresponding lower  $M_w$  CFG-1 fraction. Thus, in addition to

protein content, the high molecular weight component of CFG appears to improve the functionality for oil-in-water beverage emulsion systems.

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