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# Encapsulation of konjac glucomannan in oil droplets to reduce viscosity of aqueous suspensions and gradually increase viscosity during simulated gastric digestion

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ABSTRACT

Konjac glucomannan (KGM) is a water-soluble polysaccharide with extraordinary ability to absorb water and increase viscosity and therefore a potential strategy to increase satiety and control food intake. However, it is difficult to incorporate KGM in aqueous foods without increasing viscosity significantly. In the present work, the objective was encapsulate KGM powder as the core of oil droplets in solid/oil/water emulsions to prevent the hydration of KGM and viscosity increase. Blending soy lecithin with soy oil enabled better mixing of KGM powder and oil and enabled the encapsulation of KGM powder at a sufficiently high concentration of whey protein isolate (WPI), as indicated by low viscosities. Preheating WPI reduced the amount of proteins required to encapsulate KGM. The gradual digestion of oil droplets by pepsin at simulated gastric conditions enabled the gradual hydration of encapsulated KGM powder to increase viscosity. These results suggest the feasibility of S/O/W emulsions to deliver KGM in aqueous foods without generating a high viscosity but enabling gradual increase of viscosity during gastric digestion to potentially impact satiety and food intake.



## 1. Introduction

Controlling satiety can possibly reduce food intake during a meal or between meals and therefore may be used an intervention strategy to reduce issues caused by obesity (Marciani et al., 2001; Schroeder et al., 2013). High viscosity semi-solid foods have been shown to slow the eating and delay the gastric emptying rate which are correlated to stronger satiating properties than those less viscous (Zhu et al., 2013). Pre-meal consumption of whey proteins was shown to reduce food intake and post-meal blood glucose and insulin of subjects aged 20–27 y (Akhavan et al., 2010). Fermentable dietary fibers providing viscosities are other viable options because they provide negligible calories (Schroeder et al., 2013).

Konjac glucomannan (KGM) is such a fermentable dietary fiber that is available in the tuber of Amorphophallus konjac (Chen et al., 2014; Wang et al., 2015). KGM is composed of β-D-glucose and β-D-mannose monomers mainly linked by β(1 → 4) glycosidic bonds, with some side chains linked through β(1 → 3) glycosidic bonds (Chen et al., 2014; Tester and Al-Ghazzewi, 2013). Because human amylase cannot hydrolyze glycosidic bonds of KGM, KGM is a dietary fiber than can be hydrolyzed by β-mannase secreted by colonic bacteria (Wang et al., 2015). As a water-soluble polysaccharide with a molecular weight from 200 to 2000 kDa, KGM has an extraordinary capability of absorbing water and its solution is more viscous than any other biopolymer solutions (Wang et al., 2015). The high viscosity of KGM has been shown to inhibit appetite and slow intestinal absorption, which may be correlated to weight loss (Keithley and Swanson, 2005). In addition, KGM has been shown to reduce cholesterol, manage diabetes, beneficially impact gut microflora, among others (Tester and Al-Ghazzewi, 2013).

The strong ability to absorb water makes it challenging to incorporate KGM in moist foods and beverages without generating high viscosities. The objective of the present work was to study the possibility of encapsulating KGM powder as the core of oil droplets in solid/oil/water (S/O/W) emulsions. The exclusion of water molecules contacting KGM powder enables the delivery of the water-soluble polysaccharide as colloidal particles to reduce viscosity. When oil droplets are emulsified by digestible surfactants such as

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whey protein isolate (WPI), the gradual digestion of WPI and therefore release of KGM may enable the gradual increase of viscosity during gastric digestion, which may eliminate effects due to sudden increase of viscosity and absorption of water by KGM.

## 2. Materials and methods

### 2.1. Materials

KGM powder was purchased from NOW Foods (Bloomingdale, IL, USA). WPI was obtained from Hilmar Ingredients (Hilmar, CA, USA). Other chemicals were purchased from Fisher Scientific Inc. (Pittsburgh, PA, USA).

### 2.2. Preparation of WPI solutions

Two sets of WPI solutions were studied. In the first set, WPI powder was hydrated at 1–15% w/v in distilled water overnight at 4 °C and adjusted to pH 7.0 using 1.0 M HCl and NaOH after warming to ambient temperature (21 °C). In the second set, the 5% WPI solution as prepared at pH 7.0 was heated at 80 °C for 5 min. After cooling in a room temperature water bath, the preheated WPI solution was spray-dried using a model B290 bench-top spray dryer (BÜCHI Corporation, Flawil, St. Gallen, Switzerland). Spray drying conditions (at a feed rate of 2.5 mL/min, an inlet air temperature of 160 °C, air pressure of 600 kPa, and an outlet temperature of 110 °C) followed our previous work (Zhang and Zhong, 2015). The spray-dried powder was then hydrated to prepare solutions with 1–15% w/v preheated WPI as described previously.

### 2.3. Encapsulation of KGM powder

The encapsulation of KGM powder was carried out similar to our previous work (Zhang and Zhong, 2015) with modifications of powder preparation conditions. Briefly, 1.0 g of KGM powder was mixed with 5.0 mL corn oil and 2.33 g lecithin, followed by blending (Cyclone I.Q.$^2$ microprocessor homogenizer, VirTis Co., Gardiner, NY, USA) at 20,000 rpm for 3 min. Lecithin was used to facilitate the suspension of powder in corn oil because preliminary experiments showed unsuccessful encapsulation of KGM in treatments without lecithin. The 1 g S/O suspension was then added to 20 g of the WPI solution, and the mixture was homogenized at 10,000 rpm for 3 min using the same homogenizer. Emulsions as prepared had an overall KGM concentration of 0.63% w/w. Two independent S/O/W emulsions were prepared for following tests.

### 2.4. Viscosity of emulsions

The emulsions as prepared above were loaded onto the parallel plate geometry (40 mm in diameter and 1 mm gap) of a stress-controlled rheometer (model AR20000, TA Instruments, New Castle, DE, USA). Shear rate ramps were conducted from 0.01 to 100 $s^{-1}$ at 21 °C. A solvent trap was used to reduce moisture loss during tests.

### 2.5. Structural changes of emulsions during simulated gastric digestion

The emulsions prepared with an aqueous phase with 10% w/v WPI with and without preheating were studied. The simulated gastric juice at pH 2.0 contained 0.85% w/v NaCl and 0.32% w/v pepsin (Timchalk et al., 2010) and was mixed with the emulsion at a volume ratio of 20:1, followed by adjusting the mixture pH to 2.0 using 1.0 M HCl. Samples were loaded onto the above parallel plate geometry of the rheometer. The viscosity of samples was measured at 1.0 $s^{-1}$ for 2 h at 37 °C.

In another set of experiments, the emulsion sample prepared with preheated WPI was mixed with the simulated gastric juice containing pepsin and adjusted for pH as above. After incubation at 37 °C in a shaking water bath operating at 150 rpm (New Brunswick Scientific Co., Edison, NJ, USA) for 0, 15, 30, 60, 90, and 120 min, 0.1 mL aliquots were withdrawn and diluted 100 times before applying 10 μL of a diluted sample evenly on a freshly-cleaved mica sheet mounted on a sample disk (Bruker Corp., Santa Barbara, CA, USA). AFM imaging followed the same protocol in our previous work (Luo et al., 2014). The instrument was a Multimode VIII microscope (Bruker AXS, Billerica, MA, USA) and the rectangular cantilever with an aluminum reflective coating on the backside had a quoted force constant of 2.80 N/m (FESPA, Bruker Corp.). Topographical images were acquired at the tapping mode and a scanning speed of 1 Hz.

## 3. Results and discussion

### 3.1. Encapsulation properties

Because KGM absorbs water and increases viscosity quickly, it is difficult to exactly quantify the amount of unencapsulated KGM. Shear rate ramps were used as an indirect method to characterize

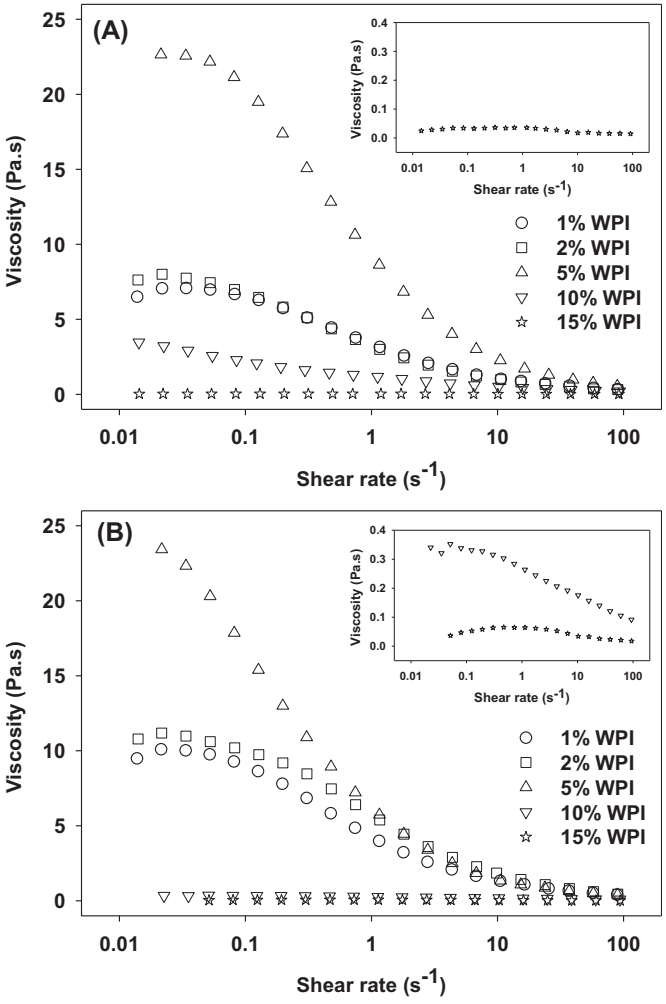


**Fig. 1.** Shear rate ramps at 21 °C of emulsions prepared with an aqueous phase with 1–15% w/v WPI without (A) and with (B) preheating at 80 °C for 5 min. Data are averages from two independent replicates.