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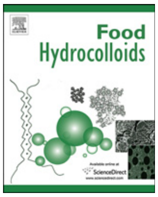

# Designing reduced-fat food emulsions: Locust bean gum–fat droplet interactions

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## A B S T R A C T

The influence of locust bean gum (LBG) on the physicochemical properties of model food sauces containing fat droplets was investigated. The particle size, microstructure, optical lightness, rheology, and storage stability of aqueous solutions and oil-in-water emulsions containing different LBG concentrations (0.05–1 wt%) were measured. Non-dissolved hydrogel microparticles were observed in both aqueous solutions and emulsions above a certain LBG level (≥0.4%). The mean particle diameter ($d_{4,3}$) and apparent viscosity of the emulsions increased steeply when the LBG concentration exceeded about 0.2–0.4%, while the lightness and flocculation stability decreased. The emulsions were highly prone to creaming and phase separation at intermediate LBG concentrations (0.2–0.8%). The changes in the physicochemical properties of the emulsions with increasing LBG concentration were attributed to a number of factors: (i) viscosity enhancement; (ii) depletion flocculation; (iii) hydrogel formation. These results have important implications for the rational design and production of reduced-fat food emulsions, such as sauces, dressings, and deserts.

## 1. Introduction

Awareness of the critical importance of diet on human health and wellness is growing among consumers, regulatory organizations, and the food industry (Chaput, Doucet, & Tremblay, 2012; Milliron, Woolf, & Appelhans, 2012). In particular, there has been increasing concern about the rise of chronic diseases related to over-consumption of calories, such as overweight, obesity, heart disease, hypertension, and diabetes. Academic, government, and industrial research laboratories have therefore been actively involved in formulating reduced-calorie foods, such as low-fat or fat-free versions of traditional food products (Hoefkens, Verbeke, & Van Camp, 2011; Nehir El & Simsek, 2012). However, reduction or elimination of fats often compromises the physicochemical attributes (optical properties, rheology, stability) and sensory quality (appearance, flavor profile, and textural attributes) of food products (Bayarri, Taylor, & Joanne, 2006; Gonzalez-Tomas, Bayarri, Taylor, & Costell, 2007; McClements, 2002a). This is because fats play multiple roles in determining the overall properties of food products, particularly when the fats are in an emulsified state. For example, fat droplets influence the appearance (optical properties), flavor profile (molecular partitioning), textural attributes (rheology), and shelf-life (stability) of food emulsions (Benjamins, Vingerhoeds, Zoet, de Hoog, & van Aken, 2009; McClements & Demetriades, 1998; Mun et al., 2009).

Food hydrocolloids (such as starches, gums, and proteins) are widely utilized in reduced-fat foods to replace some or all of the desirable characteristics normally provided by the fat droplets (Bayarri, Chulia, & Costell, 2010; Torres, Janhoj, Mikkelsen, & Ipsen, 2011). The ability of hydrocolloids to modify emulsion properties depends on many factors, including their molecular characteristics (*e.g.*, molar mass, branching, conformation, charge, hydrophobicity, concentration, and interactions) and their impact on bulk physicochemical properties (*e.g.*, light scattering, thickening, gelling, stability) (Dickinson & Stainsby, 1988; McClements, 2005). Hydrocolloids may either be used in isolation or in combination to simulate specific fat droplet properties. When used in combination they may contribute independently, synergistically, or antagonistically to particular system properties depending on the nature of the molecular interactions involved (Bayarri et al., 2010; BeMillier, 2011; Dolz, Hernandez, Delegido, Alfaro, & Munoz, 2007). Food hydrocolloids increase the viscosity of aqueous solutions, and are therefore able to provide some of the textural attributes usually associated with high fat droplet contents (Bayarri et al., 2010; Korus, Juszczak, Witczak, & Achremowicz, 2004; Singh, Kaur, &

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McCarthy, 2007). The ability of hydrocolloids to thicken aqueous solutions is also useful for inhibiting fat droplet creaming, which may occur when the fat droplet concentration is reduced below a level where the close-packing of droplets is no longer possible (Dickinson & Stainsby, 1988; McClements, 2005). Some hydrocolloids may also provide desirable optical properties to reduced-fat products due to their ability to scatter light waves and produce a cloudy appearance (Chantrapornchai, Clydesdale, & McClements, 1999). Finally, the addition of polysaccharide gums to foods may also provide desirable nutritional benefits, such as those associated with consumption of dietary fiber (Laneuville, Paquin, & Turgeon, 2005; Ward, 1997).

It should be pointed out that incorporation of hydrocolloids into emulsions may also have unintended adverse effects on reduced-fat systems. Hydrocolloid addition may accelerate the rate and extent of physical instability (creaming and phase separation) through depletion or bridging flocculation mechanisms if the type and amount of hydrocolloids added is not controlled (Coa, Dickinson, & Wedlock, 1990; Dickinson & Pawlowsky, 1997; Ye, Hemar, & Singh, 2004). Addition of some hydrocolloids may cause undesirable changes in the appearance, texture, or mouthfeel of commercial products, *e.g.*, a slimy texture or appearance.

This study is part of an ongoing research program within our laboratory to understand the major factors influencing the formulation of high quality reduced-fat food emulsions. The main aim of this study was to understand the influence of a hydrocolloid (locust bean gum, LBG) on the physical properties and stability of model reduced-fat sauces. For the sake of clarity, the study is divided into two parts. In this paper, we examine the influence of LBG addition on the properties of a simple model sauce that consisted of fat droplets dispersed within water. In a subsequent paper, we will examine the influence of LBG addition on the properties of a more complex model sauce consisting of a mixture of fat droplets and swollen starch granules.

LBG is a non-ionic highly branched water-soluble polysaccharide (Cui, 2005). It was selected for this study because it is widely used in the food industry to modify the texture and stability of food and beverage products. A previous study has examined the possibility of replacing starch with LBG and other hydrocolloids within model salad dressings (Dolz, Hernandez, & Delegido, 2008). These researchers reported that LBG addition could be used to replace part of the textural characteristics lost when starch was removed from the samples.

## 2. Materials and methods

### 2.1. Materials

Fat (Canola oil) and locust bean gum (LBG) were provided by ConAgra Foods (Omaha, Nebraska, USA). Tween® 80 was purchased from Sigma–Aldrich (St Louis, MO). The average molecular weight (MW) of the LBG used in this study was determined to be 1800 kDa by size-exclusion chromatography (*Spectrometry Facility*, University of Massachusetts, Amherst, MA). The average molecular weight was estimated using Pullulan starch as a standard (Maximum MW = 800 kDa) and double distilled water as a solvent. This molecular weight corresponds to a viscometric radius of LGB of about 90 nm (Pollard, Eder, Fischer, & Windhab, 2010).

### 2.2. Methods

#### 2.2.1. Locust bean gum dispersions

Locust bean gum dispersions with concentrations ranging from 0.05 to 1.0% were prepared. A weighed amount of LBG powder was dispersed in double distilled water (room temperature) and heated to 90 °C for 5 min holding time with continuous stirring (~400 rpm). The heated suspensions were cooled to room temperature in a water bath and were then analyzed for their physical properties. After this process, the LBG solutions had pH values around 6.3 ± 0.5.

#### 2.2.2. Oil-in-water emulsions

Oil-in-water (O/W) emulsions containing 10 wt% canola oil and 1 wt% Tween 80 were prepared. Firstly, surfactant solutions were prepared by dispersing weighed amount of Tween 80 in double distilled water and then warming at 40 °C until the surfactant was fully dissolved. Coarse emulsions were then produced by blending the oil phase and the aqueous surfactant solution together using a handheld mixer at 15,000 rpm for 60 s. The coarse emulsions produced were then passed through a two-stage homogenizer at 5000 psi for 4 passes to reduce the droplet size and degree of polydispersity (LAB 1000, APV-Gaulin, Wilmington, MA).

#### 2.2.3. Locust bean gum and emulsion mixed systems

A series of emulsions were prepared that had the same fat content (5%) but different LBG concentrations (0–1%). A weighed amount of LBG was dispersed in the 5% O/W emulsions and the mixtures were heated to 90 °C for 5 min holding time with continuous stirring (~400 rpm). The heated mixtures were then cooled to room temperature in a water bath prior to analysis. The mixed systems had pH values ranging from 6.0 to 6.3, with the pH increasing slightly with increasing LBG content.

### 2.3. System characterization

#### 2.3.1. Particle size

The particle size distribution of all the systems was measured using a laser diffraction particle size analyzer (Mastersizer 2000, Malvern Instruments, Ltd., Worcestershire, U.K.). Samples were diluted by adding small aliquots into a measurement chamber containing water until the instrument gave an optimum obscuration rate between 10 and 20%. The particle size distribution was calculated from the light scattering pattern using Mie theory. A refractive index of 1.33 was used for the aqueous phase, 1.472 for the oil phase (emulsions) and hydrogel phase (LBG microparticles). The actual refractive index of LBG microparticles was unknown, and so the particle size data obtained by light scattering on these systems should be treated with some caution. Particle size measurements are reported as volume-weighted mean diameters ($d_{4,3}$) and surface-weighted mean diameters ($d_{3,2}$).

#### 2.3.2. Microstructure analysis

The microstructure of all systems was examined using optical microscopy with a 60× objective lens and 10× eyepiece (Nikon D-Eclipse C1 80i, Nikon, Melville, NY, U.S.). A small aliquot of each sample was placed on a microscope slide and covered with a cover slip prior to analysis. The microstructure images were analyzed using image analysis software (Nikon, Melville, NY).

#### 2.3.3. Optical properties (lightness)

The lightness ($L^*$) of the samples was measured using a colorimeter (ColorFlez EZ, HunterLab, Reston, VA) with a tristimulus absorption filter (HunterLab, 2008). The lightness value ranges from 0 (*i.e.*, black) to 100 (*i.e.*, white) (HunterLab, 2008; Leon, Mery, Pedreschi, & Leon, 2006).

#### 2.3.4. Flow behavior and apparent viscosity

The apparent shear viscosity of all systems was measured using a dynamic shear rheometer (Kinexus Rheometer, Malvern