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Study on the textural and volatile characteristics of emulsion filled protein gels as influenced by different fat substitutes

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ABSTRACT

Emulsion filled protein (EFP) gels were prepared through a cold-set gelation process using denatured protein, and the effects of fat substitutes on the texture and volatile release of EFP gels were investigated. Pre-heating determined the denature degree of protein structure, and higher heating intensity resulted in higher viscosity of the emulsions, and larger storage modulus (G′) of the corresponding gels. Oil-reduced EFP gels (15% sunflower oil) were prepared with the addition of fat substitutes (medium chain triglyceride-MCT, maltodextrin, or guar gum), and they showed different properties from the full-oil counterpart (20% sunflower oil). The three tested fat substitutes were effective in enhancing G′ and stiffness of the gels, while the magnitude was dependent on the content and types of fat substitutes. The increase in the content of MCT or maltodextrin (5–15%) could lead to earlier onset of gelation, but the presence of fat substitutes did not affect the water holding capacities of the gels. With strengthened gel structures by the fat substitutes, oil-reduced gels could have decreased air-gel partition coefficients of the volatiles, particularly the more lipophilic compounds. Among the three fat substitutes, MCT and maltodextrin were more capable to retain volatiles in the gels.

1. Introduction

As a main ingredient in many foods, fat/oil plays important roles in the texture, mouthfeel, and flavor of foods. However, consumers are cautious about the intake of excessive fat, particularly the saturated fat, which has been associated with obesity, cardiovascular diseases and even cancers. For this reason, fat-free or low-fat foods are gaining more popularity in the current food market (Sandrou & Arvanitoyannis, 2010). Food scientists are also working to develop novel food ingredients (i.e., fat substitutes) to partly or fully replace fat in specific food, or to design novel food microstructures to modify the texture and flavor release of fat-reduced food, without scarifying good food perception (Akoh, 1998; Co & Marangoni, 2012).

The emulsion filled protein gel (EFP gel) is a protein gel matrix within which emulsion droplets are embedded. Commercial products of EFP gel include cheese, tofu, yoghurt, sausage, and some dairy desert (Dickinson, 2012). With soft-solid-like structures, EFP gels can be used to mimic the textural properties of saturated fat (Chung, Degner, Decker, & McClements, 2013). Several studies also reported that volatile compounds within EFP gels had lower release rates, which is favorable for the design of fat-reduced food (Malone & Appelqvist, 2003; Mao, Roos, & Miao, 2014).

The texture of protein gels can be largely described by their rheological properties, determined either through small deformation oscillatory shear tests (with rheometers), or fractural tests (with texture analyzers) (Moakes, Sullo, & Norton, 2015; Wang et al., 2017). It is now understood that the rheological properties of EFP gels are mainly dependent on the content and natures of the proteins used to build the gel structures, and also the oils which determine the interactions between oil droplets and the gel matrix (Mao et al., 2014; Torres, Murray, & Sarkar, 2016). To facilitate gelation, the protein structure has to be unfolded to expose more hydrophobic residues, which then self-aggregate to build gel network. Therefore, those environmental stresses affecting protein structures, e.g., pH, temperature, ionic strength can influence the properties of EFP gels (Dickinson, 2012; Farjami & Madadlou, 2017). In EFP gels, oil droplets (active fillers) can strengthen the gel networks when the oil-water interface has bonds with the gel matrix. The reinforcement effect of the oil phase was primarily dependent on the volume fraction of the fillers, and a higher oil content generally results in a gel with higher gel strength (Mao et al., 2014). Emulsions with smaller oil droplets usually form firmer gels, as the larger interface covering oil droplet allows stronger interactions

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with the gel matrix (Torres et al., 2016).

Gel microstructure also affects the release behaviors of the volatile compounds within (Mao, Roos, Biliaderis, & Miao, 2017). Previous studies either on pure gels (e.g., pectin gels, protein gels, carrageenan gels) or mixed gels (e.g., starch-carrageenan gels, pectin-gelatin gels) have shown that gels with higher strength had lower release rates or intensity of volatiles (Boland, Delahunty, & van Ruth, 2006; Frank, Eyres, Piyasiri, & Appelqvist, 2015; Juteau-Vigier et al., 2007). However, only limited work has been carried out on volatile release from EFP gels. Malone and Appelqvist (2003) designed biopolymer-gelled particles with encapsulated oil droplets containing volatiles. They found that the initial maximum volatile release in the mouth was reduced due to the slower mass transfer of volatile compounds through the gel structures. In a previous study (Mao et al., 2014), the authors observed that the strength of the EFP gel was more dependent on protein content than on oil content, while the release rates of most volatile compounds were more dependent on oil content. As volatile release can be physically retarded by the gel structures, release rates of the volatiles in oil-reduced EFP gels can be well slowed by increasing protein content, and similar volatile release profile can be obtained in an oil-reduced EFP gel as its full-oil counterpart (Mao et al., 2014).

EFP gels have shown great potentials in adjusting the textural and volatile characteristics of gelled food by modifying the microstructures (Dickinson, 2012; Torres et al., 2016). In the current study, we aimed to incorporate fat substitutes in EFP gels, and study the effects of fat substitutes on the texture and volatile release of EFP gels. As the role of protein in oil-reduced gels was elucidated in a previous study (Mao et al., 2014), this work focused on lipid-based and polysaccharide-based fat substitutes.

2. Materials and methods

2.1. Materials

Whey protein isolate (WPI) (BiPro) was bought from Davisco Food International (Le Sueur, MN, USA), and it contained 71% w/w β-lactoglobulin and 12% w/w α-lactabumin. Maltodextrin DE6 (MD) was the product of Roquette Freres (Lestrem, France). Medium-chain triglyceride (MCT) was kindly offered by Lonza Inc. (Williamsport, PA, USA). Guar gum (GG), glucono-δ-lactone (GDL), sodium azide, were bought from Sigma-Aldrich (St. Louis, MO, USA). Sunflower oil was purchased from a local supermarket and used without further purification. Five volatile compounds, i.e., 1-propanol (> 99.5% purity), diacetyl (> 99.5% purity), 2-pentanone (> 99% purity), hexanal (> 99% purity), and 2-heptanone (> 99% purity) were all products of Sigma-Aldrich. The selection of these compounds was mainly based on their physicochemical properties, e.g., chain length, function group, volatility, polarity.

2.2. Preparation of EFP gels

The preparation of EFP gels was detailed in a previous study (Mao et al., 2014). Briefly, WPI was dispersed in deionized water and stirred overnight. Sodium azide (0.01% w/w) was added to inhibit microbial growth. WPI solution was then heated in a water bath at different temperatures (60, 70, 85, 90 °C), followed by rapid cooling to room temperature (~23 °C) with ice-water mixture. WPI solution without heat treatment was also prepared. Emulsion was prepared by using the WPI solution as the water phase, and sunflower oil as the oil phase, and mixed at 10,000 rpm for 1 min using an Ultra-Turrax (IKA, Staufen, Germany) followed by mirofluidization (M110-EH Microfluidizer, Microfluidics International Corp., Newton, MA, USA) at 50 MPa for three passes. The full-oil emulsion contained 20% oil and 5% WPI. To obtain oil-reduced EFP gels, only 15% oil was used, and different fat substitutes were mixed either in the water phase (MD: 5, 10, 15 wt%; GG: 0.05, 0.1, 0.2 wt%) or the oil phase (MCT: 5, 7.5, 10 wt%) before emulsion preparation. To induce cold gelation, GDL (0.5 wt%) was added into the emulsions and the mixture was incubated at 25 °C for 16 h.

Droplet size of the emulsions was measured using a Zetasizer Nano-ZS90 (Malvern Instruments, Worcestershire, UK) at a fixed detector angle of 90° with the emulsions diluted at appropriated times.

Flow behaviors of the emulsions were evaluated using an AR 2000ex rheometer (TA Instruments, Crawley, UK). During the measurement, a DIN and concentric cylinder geometry (stator inner radius = 15 mm, rotor outer radius = 14 mm, gap = 5920 μm) was selected, and ~15 ml of each sample was placed into the inner cylinder, equilibrated for 2 min before measurement. Viscosity test was performed over a shear rate range of 0–300 s^{-1} at 25 °C.

2.3. Characterization of EFP gels

2.3.1. Viscoelastic properties

EFP gels were also formed in the AR 2000ex rheometer using a Din and concentric cylinder geometry. A thin layer of tetradecane oil was added to the surface of the samples to avoid water evaporation. Oscillation tests were performed at a strain of 0.5% and a frequency of 1 Hz for 16 h and the measurements were taken with an interval of 10 s. Temperature of the measurement was controlled at 25 ± 0.05 °C using a Grant GD 120 stirred thermostatic circulator (Grant Instruments, Cambridge, UK). Dynamic strain sweep measurement was previously carried out to determine the linear viscoelastic range of the samples. The evolution of storage and loss modulus (G′ and G″) of the samples during oscillation was recorded. Gelation time (T_{gel}), defined as the time point at which the G′-time curve and G″-time curve crossed over, was also reported.

2.3.2. Mechanical properties

For mechanical property analysis, the gels were formed in plastic beakers (20 mm internal diameter × 35 mm height) for 16 h at 25 °C. Penetration test was performed using a TA-HDi Texture Analyzer (Stable Micro System, Godalming, UK) with a cylindrical plunger (diameter = 5 mm) and a 5 kg load to obtain the force-distance curves of the gels. The test ran at a speed of 1 mm/s to a total penetration distance of 10 mm. Stiffness, in N/mm, defined as the initial slope of a force-distance curve was calculated (Fiszman & Salvador, 1999). The reported results were the mean values of eight replicates.

2.3.3. Water holding capacity (WHC)

To determine WHC, EFP gels formed in Nalgene centrifuge tubes (Sigma-Aldrich) were centrifuged at 20000 × *g* (Sorval RC 5B Plus, DuPont Instruments, Connecticut, US) for 30 min at 4 °C, and the weight of the released water was measured. WHC was calculated based on the following equation:

$$WHC = \frac{W_T - W_F}{W_T} \times 100\%,$$

where W_T was the total amount (g) of water in the gel and W_F was the quantity of water (g) released. Mean of three repeats was reported (Yang, Liu, & Tang, 2013).

2.4. Emulsion flavoring

Emulsion flavoring was performed before the addition of GDL for the samples containing fat substitutes and the control, and the procedure was described in a previous study (Mao et al., 2014). Briefly, volatile compounds were first dissolved in ethanol (5% v/v for each volatile), and the solution was added into emulsions in gastight glass vials (20 ml, silicone/PTFE seals) (La-pha-pack GmbH, Langerwehe, Germany) and equilibrated for 1 h. The emulsion contained 500 mg/L of each volatile. 2 g of the flavored emulsion was quickly transferred to a headspace vial (20 ml, silicone/PTFE seals) (La-pha-pack GmbH) and