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Influence of main emulsion components on the physical properties of corn oil in water emulsion: Effect of oil volume fraction, whey protein concentrate and *Lepidium perfoliatum* seed gum

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ABSTRACT

The effect of composition (whey protein concentrate, *Lepidium perfoliatum* seed gum, and oil content) of corn oil-in-water emulsions on their physical properties, droplet size and viscosity was studied using response surface methodology (RSM). For each response, a second-order polynomial model was developed using multiple linear regression analysis. The results indicated that the response surface models were significantly fitted for all response variables studied. It was shown that all emulsion components greatly influenced the physical properties of emulsion and its overall stability during storage. The main effect of *L. perfoliatum* seed gum was observed to be significant in most of response surface models. Therefore, the concentration of this gum should be considered as a critical variable for the formulation of emulsions. The overall optimum region resulted in a desirable emulsion was predicted to be obtained by combined level of 0.59% *L. perfoliatum* seed gum, 6% WPC and 21.95% oil volume fraction.

1. Introduction

Most emulsion products usually contain different components. The efficient production of high quality food emulsions depends on knowledge of the contribution that each individual constituent makes to the overall properties and how this contribution is influenced by the presence of the other constituents (McClements, 2005). Biopolymer ingredients most used in emulsion production are proteins and polysaccharides (Dickinson, 1992, 2003). Since foods are multicomponent systems, protein–polysaccharide interactions have been extensively researched in order to find new and better applications for these biopolymers (Khalloufi, Corredig, Goff, & Alexander, 2009; Wang, Li, Wang, & Adhikari, 2011; Ye, Hemar, & Singh, 2004). Proteins are present primarily as emulsion forming and stabilizing agent, whereas polysaccharides are mainly used as thickening and water holding agents. Oil volume fraction is also among the major parameters which could affect the properties of emulsion.

Proteins are often used as emulsifiers in emulsion to stabilize droplets against flocculation or coalescence (Ye & Singh, 2006). Whey protein concentrate (WPC) has been widely used as a source emulsifier. During emulsification, protein molecules are rapidly adsorbed onto the newly formed droplet surface and reduce the interfacial tension and provide a protective coating.

A polysaccharide is often added to oil-in-water emulsions to enhance the viscosity of the aqueous phase, imparts desirable textural attributes, and stabilizes the droplets against creaming (Dickinson, 1992). Among food polysaccharides, seed gums are the preferred hydrocolloids since these are comparatively cheap, nontoxic, eco-friendly and nonpolluting during production and application. Seed gums are not hydrolyzed in the human digestive tract and therefore are not a source of bioavailable calories. They are able to bind and immobilize a large amount of water thus increasing viscosity, modifying texture and stabilizing product consistency (Koocheki, Kadkhodaee, Mortazavi, Shahidi, & Taherian, 2009; Koocheki, Mortazavi, Shahidi, Razavi, & Taherian, 2009; Koocheki, Taherian, & Bostan, 2011). *Lepidium perfoliatum* seeds contain a large amount of mucilaginous substances which diffuses out when soaked in water (Koocheki, Taherian, Razavi, & Bostan, 2009). The hydrated gum can be used as a potential thickening and stabilizing agent in food industry.

Even though *L. perfoliatum* seed gum is ideal for stabilizing emulsions (Koocheki, Taherian, et al., 2009), there is a lack of sufficient knowledge on the interactions between WPC and this novel gum. The effect of oil-in-water emulsion component on its droplets characteristics, flow properties and physical stability are important for manufacturing a stable food emulsion. Therefore, the objective of this study was to investigate the effects of *L. perfoliatum* seed gum concentration and oil volume fraction on emulsions formed with different WPC content at natural pH. In the present study, response surface methodology (RSM) was applied for modeling the possible relationships between the responses and independent variables. In

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addition, a desirable formulation for making a stable corn oil-in-water emulsion was optimized.

2. Materials and methods

2.1. Materials

Commercial corn oil was obtained from local market. Analytical grade sodium azide was purchased from Merck KGaA (Germany) and commercial whey protein concentrate (WPC, code: A635) was donated by Milk Powder-Multi Company (Mashhad, Iran). *L. perfoliatum* seed gum was extracted based on the method described in our previous work (Koocheki, Taherian, et al., 2009).

2.2. Surface and interfacial tension

The surface and interfacial tensions of *L. perfoliatum* seed gum in combination with WPC were determined by the Du Nouy ring method (Kruss K100 Tensiometer, Germany) at 20 °C. Deionized water was used to calibrate the tension meter for surface tension measurements. Corn oil was used for interfacial tension determinations. The oil was added to a constant volume of an aqueous gum solution. The equilibrium time for surface tension measurements was 30 min; all tests were carried out in triplicate.

2.3. Emulsion preparation

Corn oil-in-water emulsions composed of *L. perfoliatum* seed gum (0.2–0.6% w/v), WPC (2–6% w/v) and corn oil (20–50% v/v) were prepared for the optimization procedure based on a face central composite design (FCCD, Table 1). To prepare the water phase, protein solutions with different WPC concentration and *L. perfoliatum* seed gum solution with different concentrations were prepared separately by dissolving measured quantities of WPC and gum powder into distilled water at room temperature. The solutions were kept overnight at 4 °C to fully hydrate and then mixed before emulsion preparation. While mixing the water phase, the corn oil was gradually added into water phase. Sodium azide (0.02% w/v) was added into the emulsions as an antimicrobial agent. The premix was then pre-homogenized with a laboratory rotor stator homogenizer (Ultra Turrax T-25, IKA Instruments, Germany) at a speed of 12,000 rpm for 5 min at room temperature to provide an initial coarse emulsion. The coarse emulsion was then sonified for 10 min by using a 25 kHz ultrasonic processor (model VCX 750, Sonics & Materials, Inc., USA) at a nominal maximum power output of 750 W and a cylindrical titanium sonotrode of 19 mm in diameter. The ultrasonic energy was set at 750Wand the sonotrode tip immersed 1 cm below the surface of liquid. The temperature was kept constant at 25 °C throughout sonication by circulating cooling water through the jacket of chamber. The final pH of emulsions was measured to be 7 and independent of the gum concentration.

Table 1
Matrix of the face central composite design (FCCD).

Treatment runs	*L. perfoliatum*	WPC	Oil volume
1	0.2	2	20
2	0.2	2	50
3	0.2	4	35
4	0.2	6	20
5	0.2	6	50
6	0.4	2	35
7	0.4	4	20
8	0.4 (C)	4	35
9	0.4 (C)	4	35
10	0.4 (C)	4	35
11	0.4 (C)	4	35
12	0.4 (C)	4	35
13	0.4 (C)	4	35
14	0.4	4	50
15	0.4	6	35
16	0.6	2	20
17	0.6	2	50
18	0.6	4	35
19	0.6	6	20
20	0.6	6	50

C, center point.

2.4. Emulsion droplet size analysis

Size distribution of the oil droplets were determined by a laser diffraction particle sizer (Fritsch Analysette 22, Germany) as described previously (Koocheki & Kadkhodaee, 2011). All measurements were done on freshly prepared samples and emulsions stored for 28 days at 4 °C. For calculating the rate of coalescence, the average droplet sizes were measured every week during storage. The mean droplet diameter was expressed as the Sauter diameter (D_{32}):

$$D_{32} = \frac{\Sigma n_i d_i^3}{\Sigma n_i d_i^2} (\mu m) \quad (1)$$

where n_i is the number of droplets of diameter d_i.

2.5. Rate of coalescence (K_c)

The apparent rate of coalescence largely follows the first-order kinetics as represented by the following equation (Taherian, Britten, Sabik, & Fustie, 2011):

$$N_t = N_0 \exp(-K_c t) \quad (2)$$

where N_0 and N_t are the numbers of droplets per unit volume of emulsion initially and time t, respectively, and K_c is the rate of droplets coalescence. Using mean average droplet size measured during storage, the rate of coalescence (K_c) can be determined by plotting $3(\ln (D_t/D_0))$ vs. time (t) using Eq. (5):

$$\ln D_t = \ln D_0 + \frac{K_c t}{3} \quad (3)$$

where D_0 and D_t are the average droplet sizes initially and at time t, respectively.

2.6. Creaming stability

Ten milliliters of freshly prepared emulsions were placed into glass test tube. These tubes were tightly sealed and then stored at 4 °C. Creaming of emulsions was monitored after 28 days of storage. The total height of the emulsion (*HE*) and the height of the serum layer (*HS*) were measured. The measurement was performed in duplicate samples. The extent of creaming was determined as a creaming index (Eq. (4)):

$$CI = \frac{HS}{HE} \times 100 \quad (4)$$

The *CI* provides indirect information about the extent of droplet aggregation in an emulsion; typically the more the aggregation, the larger the effective particle size and hence the faster the creaming.

2.7. Viscosity measurement

The viscosity of emulsions was measured by a rotational programmable viscometer (DV III ULTRA, Brookfield Engineering Laboratories, USA) at 25 °C using the SC4-18 and SC4-31 spindles. The measurements