

Effect of Homogenizer Types and Sodium Chloride Concentrations on the Physical Properties of Coconut Oil-in-Water Emulsions

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ABSTRACT

The influence of homogenizer types and salt concentrations (0, 25, 50, 75 and 100 mM NaCl) on the physical properties of coconut oil-in-water emulsions (20 wt%) stabilized by 0.6 wt% whey protein isolate were investigated. All coconut oil-in-water emulsions prepared from two-stage valve homogenizer gave much better stable emulsions with lower creaming index compared with those prepared from rotor/stator homogenizer. The emulsions containing NaCl exhibited shear thinning behavior. The apparent viscosity of the emulsions increased with increasing NaCl concentrations especially at lower shear rate. These results gave the information to understand the influence of homogenizer types and NaCl on the creaming and rheological properties of the coconut emulsions for product and process development.

Key words: coconut oil-in-water emulsion, NaCl, homogenizer, creaming index, rheological properties

INTRODUCTION

Many food products in the markets are in the emulsion state such as cheese, milk, salad dressings, sauces, beverages and coconut milk (Gonzalez, 1991; McClements, 1999). An emulsion is a dispersed system that consists of two immiscible liquids (usually oil and water), with one of the liquids dispersed as small droplets in the other called continuous phase (McClements, 1999). The emulsions are thermodynamically unstable systems and have a tendency to break down over time (Dickinson, 1992; Friberg and Larsson, 1997; McClements, 1999). The breakdown of an emulsion may manifest itself through different physicochemical mechanisms such as gravitational separation, coalescence, flocculation, Ostwald ripening and phase inversion (Friberg and Larsson, 1997; McClements, 2000). Therefore, the production of high quality food emulsions that can

remain kinetically stable for a certain period of time is necessary. In general, emulsifiers are needed for stabilizing emulsions because they decrease the interfacial tension between the oil and water phases and form a protective coating around the droplets which prevents them from coalescing with each other (McClements, 1999). Whey proteins commonly used as emulsifiers are amphiphilic molecules and their ability to form and stabilize oil-in-water emulsions is required for emulsion formation (Dickinson, 1997).

Mechanical emulsification is an important step in the production of emulsion-based food products because droplet-size distribution influences the properties of an emulsion (Brosel and Schubert, 1999). The emulsification process includes two steps, deformation and disruption of droplets, and the stabilization of the newly formed interface by surfactant or emulsifier. Different machines are available for emulsification such as

rotor-stator systems and high-pressure homogenizers (Brosel and Schubert, 1999).

Electrolyte ions influence the aggregation of protein-stabilized droplets in many ways such as reducing the electrostatic repulsion between droplets through electrostatic screening effect or increasing the short-range hydration repulsion between droplets which may oppose droplet aggregation (Israelachvili, 1992).

Since coconut oil-in-water emulsions, such as coconut milk and coconut cream, form the basis of many traditional Thai dishes, therefore the influence of homogenizer types for mechanical emulsification and the presence of salt in coconut oil-in-water emulsions was investigated to get a better understanding for product and process development in food industry.

MATERIALS AND METHODS

Materials

Refined coconut oil, after bleaching and deodorization, was purchased from Morakot Industries (Bangkok, Thailand). Whey protein isolate (WPI), which had a protein content of 98.0 wt% and moisture content of 4.4 wt%, was donated by Davisco Foods International (MN, USA). Sodium chloride and sodium azide were purchased from Merck Company (Darmstadt, Germany).

Emulsion preparation

An aqueous phase was prepared by dispersing 2 wt% WPI and 0.04 wt% sodium azide (NaN_3 , as an antimicrobial agent) in distilled and deionized water and stirring for at least 2 h to ensure complete dissolution of protein (modified from Kim *et al.*, 2003). A range of NaCl solutions containing different concentrations (0 to 200 mM NaCl) were prepared by dissolving NaCl in 5 mM phosphate buffer (pH 7.0).

A premixed oil-in-water emulsion (1000 g) was prepared by blending 40 wt% coconut oil and 60 wt% of 2 wt% WPI solution for 1 min using a

rotor/stator homogenizer (Ystral GmbH, drive X10-25, Ballrechten-Dottingen, Germany) with dispersing tool 20 DF at low speed (11,000 rpm) at room temperature. To compare the effect of homogenizer types on creaming stability of emulsion, some of the emulsions were further emulsified using a rotor/stator homogenizer at 19,000 rpm for 3 min (Ibanoglu, 2002), and the other were homogenized using a two-stage valve homogenizer (APV-Gaulin, model 15MR-8TA, Wilmington, MA) at 207 bar for the first stage and 34 bar for the second stage (Ye *et al.*, 2000). The pH of these emulsions was adjusted to 7.0 using 0.1 N HCl solution. All homogenized emulsions were then diluted with NaCl solutions containing different concentrations at the ratio of 1:1 to give a series of 20 wt% coconut oil-in-water emulsions containing 0 to 100 mM NaCl for investigating the creaming stability and rheological properties.

Creaming index

Fifteen grams of emulsion samples obtained from both types of homogenizers were transferred into test tubes (21 mm i.d., 86 mm height) and then stored at 30°C for 144 h (modified from Demetriades and McClements, 1998). The oil droplets, in general, have a lower density than the surrounding aqueous phase and therefore move upwards during storage leading to creaming. The height of total emulsion (H_E) and the height of the droplet-depleted lower layer (H_D) were measured every day. Creaming was reported as a “creaming index” = $100 \times (H_D/H_E)$. The creaming index provides indirect information about the extent of droplet flocculation in an emulsion: the more flocculation, the larger the particles and the faster the creaming rate.

Visual observation

The general appearance and texture of the emulsions were recorded by visual observation as low-viscosity fluid, high-viscosity fluid, low-viscosity paste, and high-viscosity paste, as well

as with or without syneresis (Demetriades *et al.*, 1997).

Rheological measurements

The rheological properties of the 20 wt% coconut oil-in-water emulsions were measured at 30°C ($\pm 0.05^\circ\text{C}$) using a Physica MCR 300 rheometer (Ostfildern, Germany) with a double gap concentric cylinder measurement cell. Emulsions were placed in the temperature-controlled measurement vessel and allowed to equilibrate to 30°C for 5 min prior to measurement. The shear stress (τ) was then recorded as a function of shear rate ($\dot{\gamma}$) range from 0.1 to 100 s⁻¹. Each shear rate was kept constant for 30 s before a measurement was made (modified from Kulmyrzaev *et al.*, 2000).

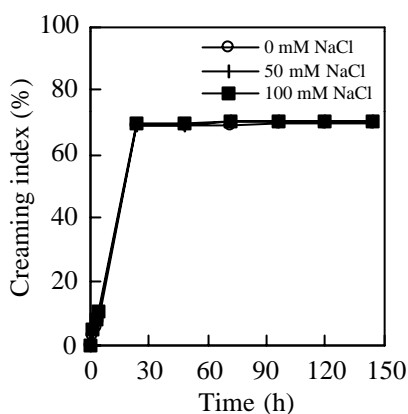
Statistical analysis

Experiments were performed in two replicates using freshly prepared samples. The average and standard deviation values were calculated from these replicate measurements.

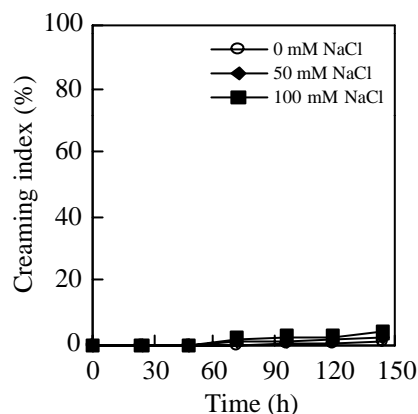
RESULTS AND DISCUSSION

Effect of homogenizer types on creaming index

The creaming index values of all emulsion samples prepared from rotor/stator homogenizer were about 69% after being stored at 30°C for 24 h (Figure 1a) and showed almost constant values after longer storage time. The results suggested that the droplet flocculation might occur after the emulsions were stored for 24 h. On the other hand, the emulsions prepared from high-pressure valve homogenizer gave very low values of creaming index (1.2 to 3.8%) even stored for 144 h (Figure 1b). Usually, the creaming stability depends on the size of droplets in an emulsion. The rotor/stator is a high-speed blender and provides the minimum droplet sizes about 2 μm in diameter (McClements, 1999) while the droplet sizes obtained from a high-pressure valve homogenizer gave the minimum droplet size of 0.1 μm . A number of studies have been shown that the size of droplets in emulsions produced by high-pressure homogenizers were less than 1 μm (Elwell *et al.*, 2004; Flourey *et al.*,



(a) Rotor/stator homogenizer



(b) High-pressure valve homogenizer

Figure 1 Comparison of creaming index of 20 wt% coconut oil-in-water emulsions containing different NaCl concentrations prepared from rotor/stator homogenizer (a) and high-pressure valve homogenizer (b) for 144 h.

2000) whereas the droplet size in emulsions produced by rotor/stator homogenizers were larger than $3\ \mu\text{m}$ (Prinderre *et al.*, 1998). The rapid increasing creaming index of emulsions prepared by using the rotor/stator homogenizer (Figure 1a) may be due to the larger droplets according to Stokes' law.

Effect of NaCl concentrations on the appearance/texture of emulsions and rheological properties

The influence of NaCl concentrations on the appearance/texture and rheological properties was investigated in the emulsions prepared by high-pressure valve homogenizer because the emulsions were more stable than those prepared from rotor/stator homogenizer considering the emulsion stability in terms of creaming index. The visual observations of the appearance and texture of the emulsions as related to ionic strength were determined by visual classifying the emulsions into 2 types; fluid and paste that had low or high viscosity and the syneresis phenomena (Demetriades *et al.*, 1997). The emulsions appeared

white opaque and homogeneous. They were as low-viscosity liquids at low NaCl concentrations during storage time. Higher NaCl concentrations gave thicker fluid emulsions. The results indicated that increasing ionic strength decreased the electrostatic repulsion between droplets because counter-ions in the aqueous phase shielded the charges on the droplet surfaces (Demetriades *et al.*, 1997). The emulsion containing 150 mM NaCl that was high-viscosity paste showed syneresis after storage for 2 days.

The viscosity measured as a function of shear rate of the emulsions containing NaCl exhibited shear thinning behavior (Figure 2): the viscosity decreasing with increasing shear rate. The emulsion without salt showed the flow properties close to Newtonian behavior. When considering the influence of NaCl concentration on apparent viscosity measured after the addition of NaCl to the emulsion for 2 h, the apparent viscosity increased with increasing salt concentrations especially when observed at lower shear rate (Figure 3). The slope of the relationships between NaCl concentration and apparent viscosity

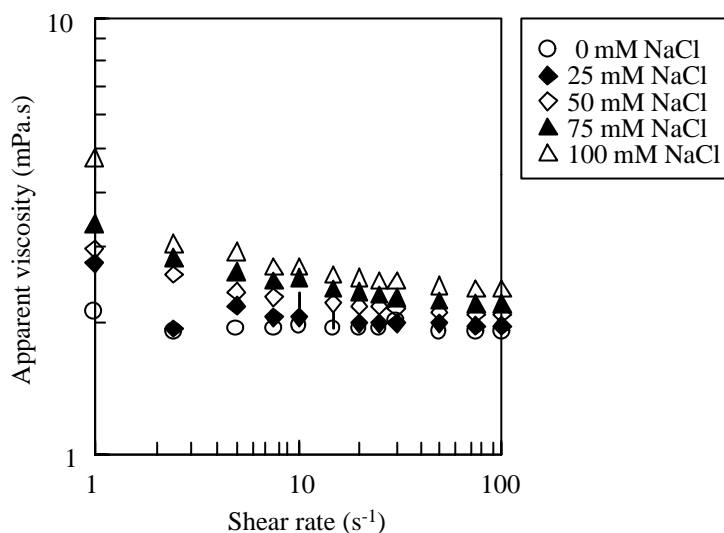


Figure 2 Apparent viscosity of 20 wt% coconut oil-in-water emulsions containing different NaCl concentrations as a function of shear rate.

(Figure 3) indicates changes of apparent viscosity with salt concentration decreased with increasing shear rate (0.0238, 0.0078 and 0.0047 mPa.s for shear rate 1, 10 and 100 s⁻¹, respectively). In the view point of process and product development, the lower shear rate condition (1 s⁻¹) implies to the condition of storage. Increasing NaCl concentration increased the viscosity of product emulsion during storage (Figure 3a). When considering the emulsions at higher shear rate (100 s⁻¹) that implies to pumping during process and transportation, the apparent viscosity was almost constant (2 to 3 mPa.s) at all NaCl concentrations (Figure 3c).

Over the range of shear rates, rheological properties of the emulsions with and without additional NaCl could be described by the power law equation: $\tau = m\dot{\gamma}^n$, where τ is the shear stress, m and n are constants called consistency index and power index, respectively. The consistency index, m , is an indicator of the viscosity of the system (Dickinson, 1992; Demetriades *et al.*, 1997). This value increased with increasing NaCl concentrations (Figure 4a) ($r^2 = 0.99$). In general, the power index (n), from the power law model equals to 1 for Newtonian fluid and less than 1 for shear thinning fluid. The emulsion without

additional NaCl had n value closed to 1 while the emulsion containing salt showed the power index less than 1 and was lower with increasing NaCl concentrations (Figure 4b).

CONCLUSION

All coconut oil-in-water emulsions (20 wt%) stabilized by whey protein isolate prepared from two-stage valve homogenizer gave much better stable emulsions with lower creaming index compared with those prepared from rotor/stator homogenizer. The emulsions containing NaCl exhibited shear thinning behavior. The apparent viscosity of the emulsions increased with increasing NaCl concentrations. These results gave the understanding the influence of homogenizer types and NaCl on the creaming and rheological properties of the emulsion systems.

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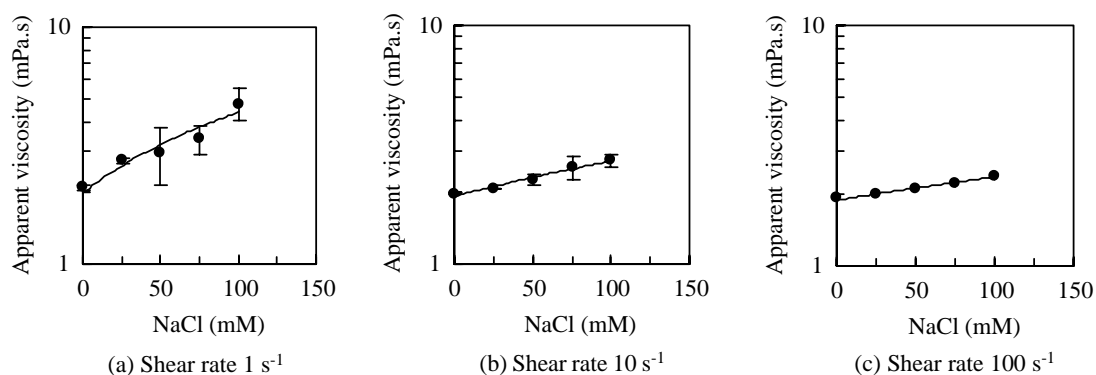


Figure 3 Dependence of apparent viscosity (at 1, 10 and 100 s⁻¹) of 20 wt% coconut oil-in-water emulsions stabilized by WPI on NaCl concentration at pH 7.

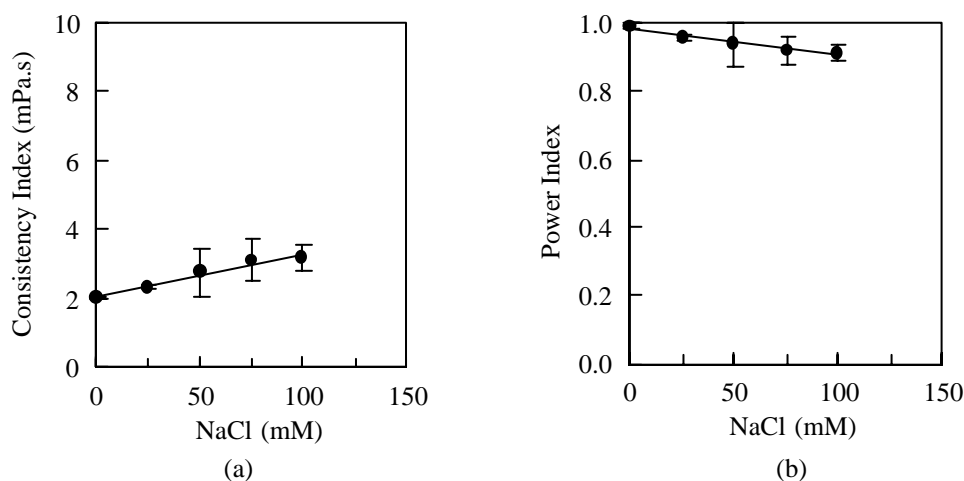


Figure 4 Dependence of the consistency index (a) and the power index (b) of 20 wt% coconut oil-in-water emulsions stabilized by WPI on NaCl concentration at pH 7.

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