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学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

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学位論文題目：
Title of Dissertation

Physico-Chemical Properties of Soy Soluble Polysaccharide (SSPS) Oil-in-Water Emulsions: Effect of SSPS Type, Dispersed Phase Type and Addition of Stabilizing Polysaccharides
（大豆水溶性多糖類 (SSPS) による O/W エマルションの物理化学的特性 ―SSPS の種類、分散相の種類及び安定剤として添加した SSPS 以外の多糖類の影響―）

学位論文要約：
Dissertation Summary

Food and food product colloids and emulsions are considered as the most complicated systems whose microstructure and factors affecting stability are difficult to study. Natural foods are composed of many constituents including fats, oils, proteins, carbohydrates and small molecular weight molecules such as vitamins and enzymes, existing in complex mixtures and molecular structures. Each component plays a significant role in determining the long term stability and the overall food quality. Among the natural food components, amphiphilic compounds are of major interest in this thesis. An amphiphilic compound is described as a chemical compound possessing both hydrophilic (water-loving or polar) and lipophilic (fat-loving) properties. These molecules can be named emulsifiers, stabilizers, or dispersing agents since they possess surface-active characteristics. Many processed food systems contain emulsifiers. Food emulsions are therefore a very important sector of the food industry. Recently, more and more consumers have become more conscious about their health condition, giving a lot of pressure on the food manufacturers. Consumption of natural foods has been encouraged from all corners of the globe, resulting in an increased number of consumers who check the food label to see the ingredients. Synthetic food emulsifiers are henceforth becoming less popular in the food industry. The search for new viable natural emulsifiers is therefore an area of current interest to many food scientists and producers.

In this regard, soy soluble polysaccharide (SSPS), extracted from the by-product of soy protein isolation (okara in Japanese), is a newly found natural emulsifier that has been proven to be an excellent emulsifier with comparable characteristics to other established emulsifiers. Hence, it is the aim of this thesis to fully characterize the physico-chemical characteristics of emulsions produced by different types of SSPS. Successful characterization of SSPS stabilized emulsions may lead to improved awareness of the existence of SSPS and its capabilities.

The effect of SSPS type (i.e. SSPS-L; SSPS-M; and SSPS-H differentiated by their respective extraction conditions) and the type of oil (i.e. Perilla seed oil - PSO; palm kernel oil - PKO; and n-Hexadecane) was examined through analysis of the differences in average droplet diameter, droplet size distribution (DSD) and emulsion rheological properties. The three different types of SSPS where characterized in terms of their respective sugar and protein compositions and the values are as reported in Table 1 below. Minute differences in the extraction conditions resulted in the differences in the sugar and protein composition of the resulting SSPS sample. From this information, it was expected that the emulsification behavior of different types of SSPS can be different and the physico-chemical properties of their formed emulsions may differ as well. Given such a background, experiments were setup to reveal any differences if at all they existed.

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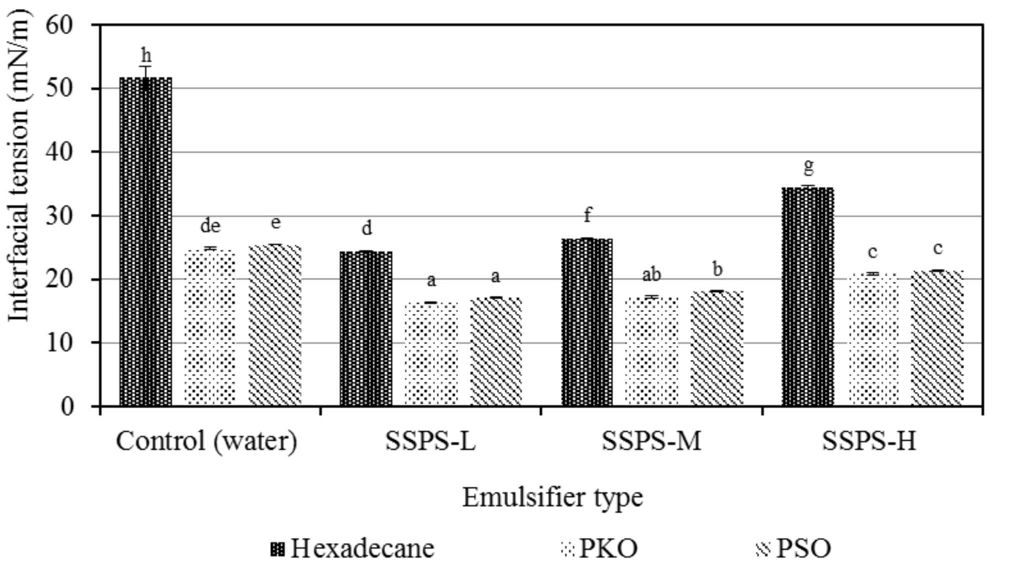
Table 1: Monosaccharide compositions of different types of soybean polysaccharide (SSPS).

Type of SSPS	Sugar composition (mol %)							Protein
	Rha	Fuc	Ara	Gal	Xyl	Glc	GalA	(dry %)
SSPS-L[a]	4.3	1.5	15.3	48.3	1.5	1.6	27.5	8.2
SSPS-M[a]	4.1	2.4	20.1	47.2	1.2	1.1	23.9	5.9
SSPS-H[b]	2.5	1.1	21.0	43.7	6.4	5.4	19.9	5.1

Rhamnose (Rha), Fucose (Fuc), Arabinose (Ara), Galactose (Gal), Xylose (Xyl), Glucose (Glc), Galacturonic acid (GalA). [a]Nakamura *et al*., 2004; [b]Nakamura *et al*., 2012.

To begin with, the interfacial tension of the three different types of SSPS was evaluated and results are shown in Fig. 1. Oil/water interfacial tension strongly depended on SSPS type. SSPS-L was the most capable in reducing interfacial tension against PSO, PKO and hexadecane followed by SSPS-M and lastly SSPS-H.



Data are reported as means from three independent replications (n = 3) for each sample. Means which have different letter superscripts are significantly different ($p < 0.05$).

Figure 1: The interfacial tension between three types of oil (PKO; PSO; & hexadecane) and water or 1 %wt. SSPS solution (SSPS-L; -M; or -H) measured at 25 ^{0}C.

Irrespective of oil type, at 20 % oil content, SSPS-L and M were better emulsifiers for achieving small droplets probably due to their high protein content as shown in Table 1. Generally, the emulsifying power of SSPS depended on the composition of the polysaccharide and the type of lipid being emulsified. Irrespective of lipid type, emulsions droplet size (EDS) of no less than 0.7 µm could be achieved with SSPS-L and -M as sole emulsifiers at considerably low concentrations compared to most surface active polysaccharides. Higher homogenization pressures could not achieve smaller EDS, but rather produced bigger EDS, especially with SSPS-H, due to “over-processing”. Both SSPS (type L and M) solutions and their respective emulsions regardless of oil type exhibit Newtonian flow behavior while SSPS-H solution and the respective emulsions show shear-thinning behavior. Therefore, products that do not focus on particularly small EDS but rather designed for high viscosity and shear-thinning characteristics should employ SSPS-H as an emulsifier at either conventional or higher homogenization pressures. Emulsion viscosity was influenced by both SSPS and oil types with SSPS-H and hexadecane producing high viscosity emulsions. Due to high Laplace pressure of hexadecane, resulting emulsions had high viscosity and large EDS compared to emulsion systems of PKO and PSO.

Obtaining a stable oil-in-water (O/W) emulsion remains to be a great challenge for the food industry and it is here that the non-adsorbing hydrocolloids find their role. Various researchers have reported the use of

non-adsorbing hydrocolloids as stabilizers in food emulsions so as to improve creaming stability. Substantial increase in the aqueous phase viscosity is the primary key to arrest emulsion droplet movement, thereby improving creaming stability. With this idea in mind, the effect of incorporating xanthan gum (XG) or guar gum (GG) in SSPS stabilized O/W emulsions was studied. The emulsions contained 6 %wt. of SSPS, 20 %wt. Perilla Seed Oil (PSO), an omega-3 vegetable oil, and variable amounts of XG or GG ranging from 0.03 to 0.3 %wt. The presence of minute amounts of XG or GG in fresh emulsions significantly decreased the emulsion droplet size (EDS) although such low concentrations did not provide enough continuous phase viscosity to arrest creaming. Emulsion creaming stability, droplet polydispersion, and droplet sizes were improved by the presence of polysaccharide dispersions. The high continuous phase viscosity in XG or GG incorporated emulsions was responsible for improved homogenization efficiency and inhibition of emulsion droplet movement resulting in promoted stability. Emulsion microstructure indicated the presence of flocculation even at high concentrations of XG or GG caused by a depletion mechanism. All emulsions with XG or GG exhibited pseudoplastic behavior while the control emulsions showed an almost Newtonian behavior. Emulsion droplet polydispersion generally decreased with increase in the continuous phase viscosity indicating the importance of continuous phase viscosity in the dissipation of shear energy throughout the emulsion during homogenization. Therefore, manipulation of the emulsion continuous phase viscosity can be used to produce stable emulsions of different droplet sizes for different applications.

Application of SSPS and other hydrocolloid emulsifiers in real food products was attempted. The aim of this study was to assess the possibility of employing hydrocolloid emulsifiers as sole emulsifiers in combination with XG as a thickener and stabilizer to formulate mayonnaise-like O/W emulsions. Moreover, different rheological models were tested to find an appropriate model that can be used to correlate the shear rate and shear stress data. Hydrocolloid emulsifiers, SSPS, gum arabic (GA), and octenyl succinate starch (OSA-S), were investigated for their ability to produce O/W mayonnaise-like emulsions. XG was used as a stabilizer and thickener. All the three types of hydrocolloid emulsifiers were capable of emulsifying huge amounts of oil although contents above 60 %wt. could not be completely emulsified. Some floating oil could be observed on top of the emulsion samples immediately after preparation. Accelerated emulsion stability depended on the amount of dispersed phase with higher dispersed phase contents conferring more stability due to a strong network of droplets formed in the system. The formation of Pickering emulsions was confirmed in OSA-S stabilized emulsions. SSPS and GA stabilized mayonnaise-like emulsion systems satisfied the Power Law rheological model while OSA-S stabilized mayonnaise-like emulsions satisfied the Herschel-Bulkley model and showed an apparent shear thinning behavior similar to the traditional mayonnaise. The results obtained in this study open new avenues into the replacement of egg yolk in production of mayonnaise.

The results obtained in this thesis may contribute to the knowledge of the physico-chemical properties of food emulsions produced by different types of SSPS. This information might be used as a reference by food producers who may find interest in adopting SSPS as a legitimate emulsifier for formulating various food systems like ice creams, yoghurts and mayonnaise among others.