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Research Article

Functional properties of sesame protein concentrates from sesame meal

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Abstract

Three sesame protein concentrates were prepared from defatted sesame flour (DSF) by two different methods; (i) salt solution and isoelectric precipitation (SPC-salt) and (ii) alkali solution pH 9 or pH 11 and isoelectric precipitation (SPC-pH 9 and SPC-pH 11). Protein recovery and chemical composition of sesame protein concentrates were determined and some of their functional properties were investigated in comparison with soy protein isolate (SPI). The protein recoveries in SPC-salt, SPC-pH 9 and SPC-pH 11 based on Kjeldahl procedure were 19.5%, 21.9% and 35.3%, respectively. Protein contents of SPC-pH 9 (82.9%) and 11 (83.3%) was higher than those of SPC-salt (75.5%). The minimum protein solubility of all SPC samples was found at pH 5. All SPC samples were more soluble than SPI at pH 3, 8 and 9. Emulsion activity index (EAI) of all SPC samples was superior to those of SPI, while emulsion stability index (ESI) of all SPC samples was inferior to those of SPI. Water holding capacity, fat absorption capacity and foaming properties of SPC samples were lower than those of SPI

Keywords: defatted sesame flour, isoelectric precipitation, soy protein isolate, chemical composition, solubility, EAI, ESI, Thailand

Introduction

Sesame (*Sesamum indicum L.*) is an important oilseed which is cultivated in many tropical countries. In 2007, the Thai Office of Agricultural Economics reported that approximate sesame production and farm value in Thailand were 43,000 tons and 1,030 million baht, respectively [1]. Aside from being an important source of edible oil, sesame seed is an essential ingredient for traditional Asian food and desserts.

Sesame seed is composed of about 47.8-52.2% oil, 26.9-25.8% protein and 4.7-5.6% ash [2, 3] In the sesame oil industry, sesame seed is commonly used as the raw material for oil extraction, either using organic solvents or by mechanical pressing. The sesame meal is by-product after oil extraction. It is usually fed to animals as a protein source. The meal is good source of nutrition,

containing approximately 50% protein [4]. This meal has high potential for use as a protein source or as an ingredient in the food industry. Sesame protein isolates or concentrates normally are prepared by isoelectric precipitation and salt precipitation [3, 4, 5, 6]. If a sesame protein ingredient is going to find widespread application as an ingredient in the food industry, it is important to know its functional properties, for example solubility, water holding capacity, fat absorption capacity, emulsifying properties and foaming properties. Few studies have been done on the functional properties of sesame proteins from defatted sesame meal [3, 4, 5, 6]. Therefore, the objective of this the study was to examine some functional properties of sesame protein concentrates in comparison with soy protein isolate.

Materials and Methods

Materials

Sesame meal used as a source of sesame protein throughout this research was obtained from the Learning Organization and Development Centre of Sesame for Sustainable Agro-Household Industry, Faculty of Agriculture, Ubonratchatani University, Thailand. Soy protein isolate (SPI) was obtained from Thai Food (Thailand) Ltd. The powdered SPI had a composition of 81.4% protein, 0.1% fat, 5.0% moisture, 2.2% ash, 0.8% fibre and 11.2% carbohydrate. All general chemicals used in this study were of analytical grade.

Methods

Preparation of defatted sesame flour

Defatted sesame flour (DSF) was prepared following the method of Inyang and Iduh [4]. Sesame meal was vacuum-dried (Binder, VD115, Germany) at 50^0C for 1 h and then finely sieved through an electric grater. The sesame meal was defatted with hexane at a ratio of 1:4 (w/v) under constant shaking (Innova, New Brunswick Scientific, USA) at 220g for 1 h. The hexane was changed three times and then decanted and removed in a forced-air oven at 60^oC for 1 h. The DSF obtained had a final fat content of < 2%. The DSF was ground to pass through 75 mesh and kept in vacuum containers at 4^oC prior to use.

Preparation of sesame protein concentrates

Two different methods for sesame protein concentrate (SPC) were studied to establish the processing conditions for the maximum separation of the protein from DSF.

Alkali solution and isoelectric precipitation

SPC was prepared according to the method developed by Gandhi and Srivastava [3], with some modifications. DSF was mixed with water at a ratio of 1:10 (w/v). The pH of the suspended sesame meal was adjusted to pH values ranging from 7 to 12 using 2.0 M NaOH, continuously stirred with a magnetic stirrer for 1 h and centrifuged at 2,822g for 15 min. The soluble phases were adjusted to pH 4.5 using 0.1 or 1.0 M HCl which led to the precipitation of protein. The suspensions were centrifuged at 2,822g for 15 min, after which the supernatant was poured away and the precipitates were weighed and assayed for protein content by the Kjeldahl method. The precipitates were neutralized to pH 7.0 using 0.1 or 1.0 M NaOH, dialyzed by distilled water overnight at 4^oC and then freeze-dried. The sesame protein concentrate by alkali solution and isoelectric precipitation was called SPC-pH.

Salt solution and isoelectric precipitation

SPC was prepared according to the procedure of Rivas, *et al.* [5] with some modifications. DSF was suspended in 0.0 to 5.0 M NaCl at a ratio of 1:10 (w/v) at pH 7. The suspended sesame meal was stirred with a magnetic stirrer for 1 h and then centrifuged at 2,822g for 15 min to separate solution phases. The soluble phases were adjusted to pH 4.5 using 0.1 or 1.0 M HCl which led to the precipitation of protein. The suspensions were centrifuged at 2,822g for 15 min

after which the precipitates were collected and analyzed for protein content by the Kjeldahl method. The precipitates were neutralized to pH 7.0 using 0.1 or 1.0 M NaOH, dialyzed by distilled water overnight at 4^{o}C and then freeze-dried. The sesame protein concentrate by salt solution and isoelectric precipitation was called *SPC-salt*.

Protein recovery and chemical composition analysis

The chemical composition of sesame meal, DSF and SPC were determined according to AOAC standard methods [7]. The carbohydrate content was estimated by subtracting the sum of percentage of moisture, crude fat, crude protein and ash contents from 100%. The protein recovery was calculated as follows;

$$\text{Protein recovery (\%)} = \frac{\text{weight (g) of SPC X protein content (\%) of SPC}}{\text{weight (g) of DSF X protein content (\%) of DSF}} \text{ X } 100 \quad (1)$$

Determination of some functional properties

Protein solubility (PS)

SPC solutions (2% w/v) were prepared with dispersing powdered protein into distilled water adjusted to pH 3 to 9. The protein solutions were stirred with a magnetic stirrer at 4^{0}C overnight, centrifuged at 2,822g for 30 min. The protein sample was directly solubilized by 0.5 M NaOH for determination of total protein. The protein content of the supernatants was determined by the Biuret method [8] using bovine serum albumin (BSA) as a protein standard. Protein solubility was calculated as: PS (%) = 100 x P_S/P_T, where P_S is the protein content in the supernatant after centrifugation and filtration, and P_T is the total protein content present in the protein sample.

Water holding capacity (WHC) and Fat absorption capacity (FAC)

WHC and FAC of SPC were determined by the method of Gandhi and Srivastava [3]. One gram of the sample was mixed with 10 ml distilled water or soybean oil in centrifuge tubes and then allowed to stand for 30 min. Samples were centrifuged at 2,822g for 30 min. The supernatant was discarded and the tube was weighed. WHC (grams of water per gram of sample) was calculated using the equation;

$$WHC = (W_2-W_1)/W_0 \quad (2)$$

where W_0 was the weight of the dry sample (g), W_1 was the weight of the tube plus dry sample (g) and W_2 was the weight of the tube plus sediment (g).

FAC (grams of oil per gram of protein) was calculated using the equation;

$$FAC = (F_2-F_1)/ F_0 \quad (3)$$

where F_0 was the weight of the dry sample (g), F_1 was the weight of the tube plus dry sample (g) and F_2 was the weight of the tube plus sediment (g).

Emulsifying properties

Emulsifying activity index (EAI) and emulsion stability index (ESI) of SPF were measured by the method of Lopez, *et al.* [9]. SPC (4 g) were suspended in distilled water (100 ml). The protein solution was stirred with a magnetic stirrer for 30 min and then centrifuged at 2,822g for 30 min. The supernatant was collected and determined by the Biuret method [7] using bovine serum albumin (BSA) as the protein standard. To prepare the emulsion, 60 ml of protein solution and 20 mL of soybean oil were homogenized at high speed for 1 min by a homogenizer (Robot Doupe MP450C, USA). The emulsion was then diluted 200 fold with 0.1% (w/v) SDS,

containing 0.1 mol/L sodium chloride at pH 7.0. The absorbance of the diluted emulsion was then measured at 500 nm in a 1 cm path length cuvette at 0 min (A_0) and 10 min (A_{10}) after preparation using spectrophotometer (HACK DR4000, USA). EAI and ESI were calculated as follows:

$$\text{EAI } (m^2g^{-1}) = (2 \times 2.303 \times A_0 \times N)/(C \times \phi) \quad (4)$$
$$\text{ESI (min)} = (A_0 \times 10)/(A_0-A_{10})$$

where N represents a dilution factor; ϕ is the oil phase volume (ϕ of soybean oil = 0.25) and C is the concentration of protein (mg/ml).

Foaming properties

Foaming capacity and foaming stability were determined by the method of Khalid, *et al.* [10]. Three grams of SPC and one hundred ml of distilled water at pH 7 were homogenized at high speed for 5 min by homogenizer (Robot Doupe, MP450C, USA) and then transferred to a measuring cylinder. The volume of foam at 30 s was calculated and the volume increase expressed as percent foam capacity. The foam stability measured the decrease in volume of foam as a function of time up to a period of 90 min.

Statistical analysis

Triplicates of data were used for the analysis. The obtained data were analyzed using one way analysis of variance (ANOVA). Means were compared by Duncan multiple range test (DMRT) with mean square error at 5% probability (SPSS 11.5 for Windows statistical software).

Results and Discussion

Chemical composition and protein recovery of sesame protein concentrates (SPC)

The chemical compositions of sesame meal, DSF, sesame protein concentrate (SPC) by alkali solution and isoelectric precipitation (SPC-pH) and sesame protein concentrate by salt solution and isoelectric precipitation (SPC-salt) are shown in Tables 1 and 2. Extraction of oil from sesame meal led to increased chemical compositions of DSF. The protein content in DSF increased, which was 41.2% higher than in sesame meal. Similar results were reported by Inyang and Iduh [4], who found that protein content increased from 24.1% in dehulled sesame seed to 59.7% sesame flour. The high protein content in DSF could be considered as a potential source that could be used in protein concentrates.

Table 1. Proximate composition[a] (%) of sesame meal and defatted sesame flour (DSF).

Constituents	Sesame meal	DSF
Moisture	7.92 ± 0.25	2.19 ± 0.03
Fat	27.83 ± 0.23	1.49 ± 0.12
Protein[b]	30.56 ± 0.40	41.15 ± 0.96
Fiber	6.22 ± 1.22	3.46 ± 0.63
Ash	5.27 ± 1.21	6.15 ± 0.88
Carbohydrate[c]	28.14 ± 2.35	49.02 ± 0.52

[a] values are from three replication
[b] 6.25 was used as the nitrogen conversion factor
[c] Estimated by difference

The recovery of proteins in SPC-salt and SPC-pH are presented in Figures 1 and 2. For SPC-salt, the protein recovery increased as the concentration of NaCl increased to 2.0 M and then decreased as the concentration of NaCl increased from 2.0 to 5.0 M (Figure 1). This is because of the salting-in process. The salt ions interact with oppositely charged groups, which in turn

decreases electrostatic attraction between protein molecules and causes the proteins to become more solvent [11]. The highest protein recovery was found at 2.0 M NaCl (20%), while the lowest protein recovery was found at 0.0 M NaCl (0.5%). Beyond 2 M NaCl, recovery of the protein decreased (salting-out). This salting-out effect results from the competition between the protein and the salt ions for the water molecules necessary for their respective solvency. At high salt concentrations, there are not enough water molecules available for protein solvency, since the majority of the water molecules are strongly bound to the salts. Thus, protein-protein interactions become more powerful than protein-water interactions. This may lead to reduced solubility [12].

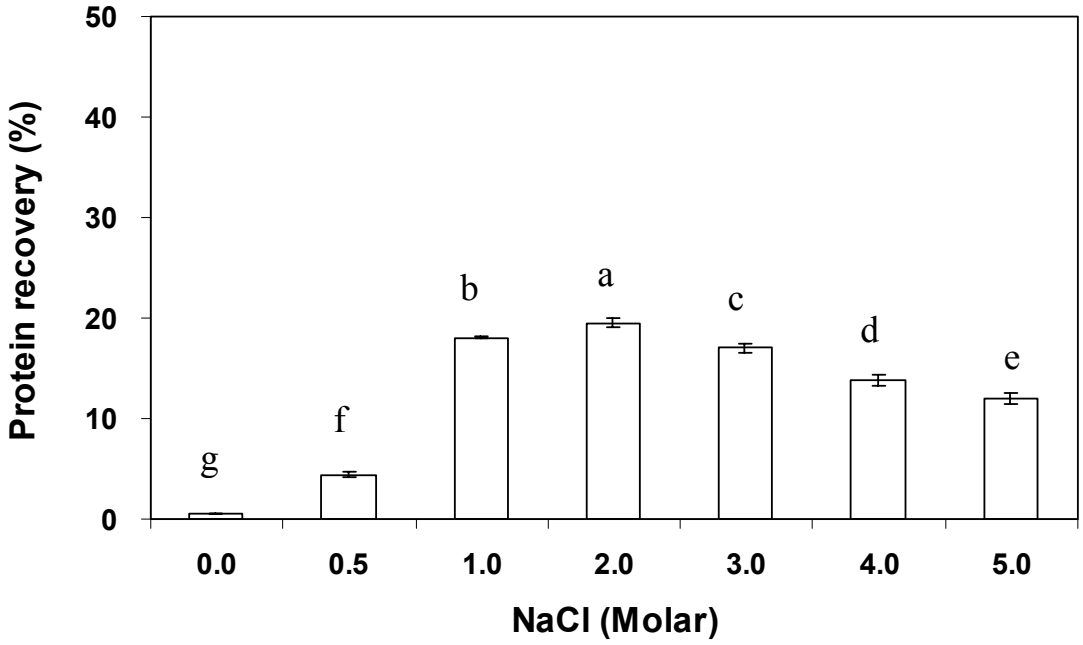

Figure 1. Protein recovery of sesame protein concentrates by salt extraction at 0-5 M NaCl and isoelectric precipitate.
DMRT (p<0.05) values are presented as a bar. Columns with different letters are significantly different (p<0.05).

For SPC-pH, the protein recovery ranged from 7.1-35.3% (Figure 2). The protein recovery of SPC-pH increased when the pH increased from 7 to 12. The highest protein recovery was found at pH 11 (35.3%), while the lowest protein recovery was found at pH 7 (7.1%). This may be because the solubility and extractability at an alkaline pH can be enhanced by increasing the net electrical charge of the protein. After salt and alkaline extraction proteins, the proteins were precipitated at their isoelectric point (pH 4.5). The percentages of the protein recovered after precipitation at the SPC-salt related to solubility of the protein. The 2 M NaCl concentration was chosen for the extraction of protein from DSF, while pH 9 and 11 were chosen for the extraction of protein from DSF. The protein recovery in 2 M NaCl extraction (SPC-salt) (20%) was lower than those in pH 9 (SPC-pH 9) (21.9%) and pH 11 (SPC-pH 11) (35.3%)**.** These results indicated that alkali solution and isoelectric precipitation appeared more effective than salt solution and isoelectric precipitation.

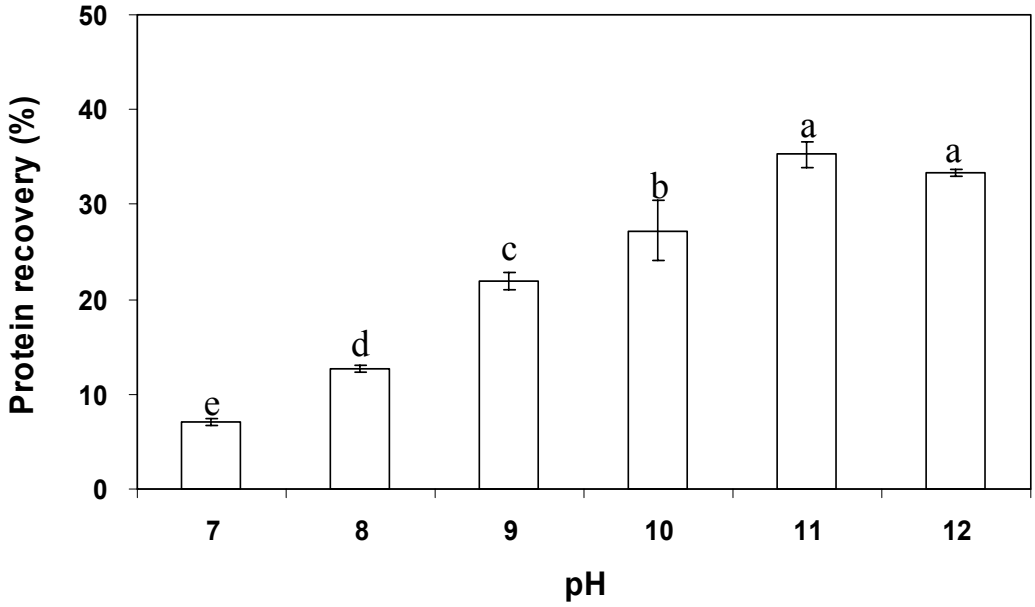

Figure 2. Protein recovery of sesame protein concentrates by alkali extraction at pH 7-12 and isoelectric precipitate.
DMRT (p<0.05) values are presented as a bar. Columns with different letters are significantly different (p<0.05).

The chemical composition of SPC-salt, SPC-pH 9 and SPC-pH 11 are shown in Table 2. The SPC-pH 9 and 11 had higher protein content (82.9 and 83.3%) than those of SPC-salt (75.5%). This result indicated that differences in preparation process affect proximate compositions of protein content. SPC contained a high amount of protein, which was slightly higher than that reported by Inyang and Iduh [4] (70.7%).

Table 2. Proximate composition[a] (%) of sesame protein concentrates by alkali extraction at pH 9 and pH 11 (SPC-pH 9 and SPC- pH 11) and salt extraction (SPC-salt).

Constituents	SPC-pH9	SPC-pH11	SPC-salt
Moisture	5.65 ± 0.17	7.87 ± 0.15	7.17 ± 1.56
Fat	1.32 ± 0.06	1.76 ± 0.06	0.51 ± 0.05
Protein[b]	82.93 ± 2.83	83.25 ± 1.52	75.49 ± 1.62
Fiber	1.05 ± 1.09	1.58 ± 1.68	0.87 ± 0.13
Ash	1.78 ± 0.24	2.48 ± 0.06	4.72 ± 0.10
Carbohydrate[c]	8.32 ± 2.83	4.63 ± 1.70	11.25 ± 1.56

[a] values are from three replication
[b] 6.25 was used as the nitrogen conversion factor
[c] Estimated by difference

Functional properties of sesame protein concentrates

Protein solubility

The protein solubility of SPC-salt, SPC-pH 9 and SPC-pH 11 was determined in comparison with soy protein isolate (SPI) (Figure 3). The pH-solubility profiles were similar for all proteins, with the solubility having a U-shaped curve. The minimum protein solubility of SPC-salt, SPC-pH 9, SPC-pH 11 and SPI was observed at pH 5 (2.6% for SPC-salt, 1.6% for SPC-pH 9, 1.2% for SPC-pH 11 and 10.3% for SPI), which is close to the isoelectric points (pI) of sesame protein isolate [6, 10]. The profiles showed that the protein solubility of SPC-salt, SPC-pH 9, SPC-pH 11 and SPI increased when the pH was altered either below or above the pI. At pH above a value

of 3 and below values 8-9 pI, all the SPCs exhibited higher solubility than those of SPI. This result was in agreement with the work reported by Lopez, *et al.* [9]. The relatively low protein solubility near their pI values can be attributed to the fact of having a low net charge, so that there is little electrostatic repulsion between them. In addition, there may even be an electrostatic attraction between positively charged patches on one protein molecule and negatively charged patches on another. At pH values above or below the pI, the protein has a net negative or positive charge, and so there is a strong electrostatic repulsion and ionic hydration forces between the protein molecules, which prevents them from aggregating and leads to a greater protein solubility [11]. These differences in solubility could have been due to differences in the type of proteins present, the intrinsic solubility characteristics of these proteins, the denaturation states of the proteins and the presence of any impurities that could affect solubility (such as minerals or polar lipids).

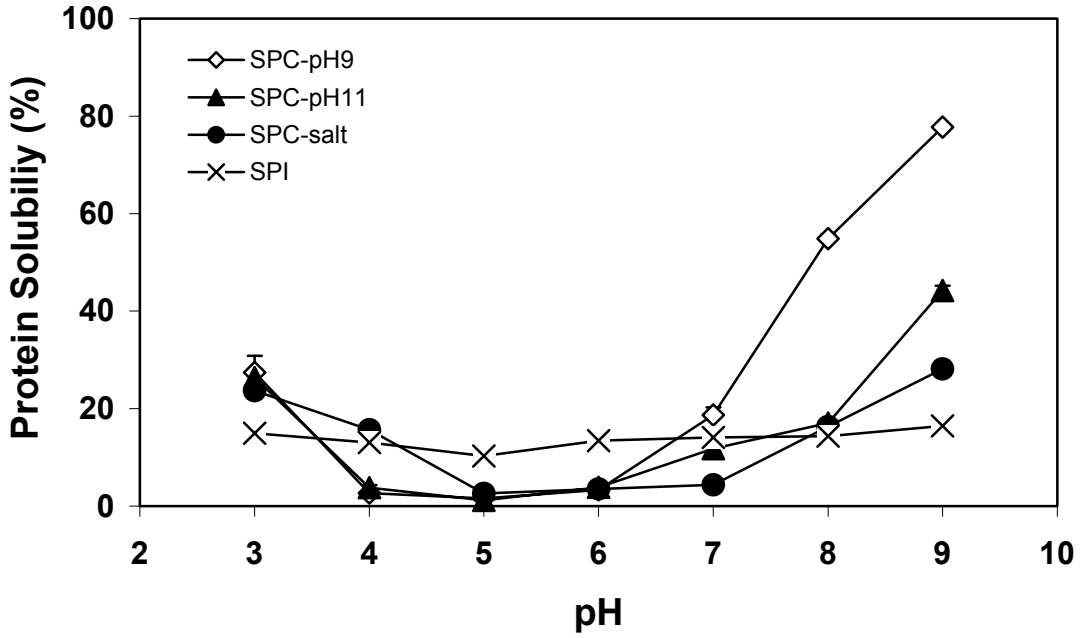

Figure 3. Protein solubility of sesame protein concentrates by alkali extraction at pH 9 and pH 11 (SPC-pH9 and SPC-pH11) and salt extraction (SPC-salt) in comparison with soy protein isolate (SPI) as related to pH range of 3 to 8 in distilled water.

Water holding capacity (WHC) and fat absorption capacity (FAC)

Water holding capacity (WHC) and fat absorption capacity (FAC) of SPC-salt, SPC-pH 9 and SPC-pH 11 were studied in comparison with soy protein isolate (SPI) (Table 3). The WHC of SPC-pH 9 (2.0 g of water/g of protein), SPC-pH 11 (3.5 g of water/g of protein) and SPC-salt (2.3 g of water/g of protein) were significantly ($p< 0.05$) lower than those of SPI (6.1 g of water/g of protein), but similar to those reported by Khalid, *et al.* [10] (2.1 ml of water/g of protein) and Gandhi and Srivastava [3] (1.9 ml of water/g protein). When the WHC of SPC was compared to other proteins, SPC showed similar values with the WHC of buckwheat protein (3.3 g water/g protein), rice bran protein concentrate of *Basmati 370* rice (3.9 g water/g protein), but was lower than soy protein isolate (7.3 g water/g protein) [13, 14]. Aletor, *et al.* [15] reported that WHC values ranging from 1.49 to 4.72 (g/g) are considered critical in viscous food such as soups and gravies. It indicates that SPCs possess good water absorption capacity and can be used in products requiring high water retention.

Table 3. Water holding capacity (WHC), fat absorption capacity (FAC) of sesame protein concentrates by alkali extraction at pH 9 and pH 11 (SPC-pH 9 and SPC-pH 11) and salt extraction (SPC-salt) in comparison with soy protein isolate (SPI).

Sample	Water holding capacity[1] (g of water /g of protein)	Fat absorption capacity [1] (g of oil /g of protein)	Emulsion activity index (EAI)[1] (m^2/g)	Emulsion stability [1] (min)
SPC- pH 9	1.98 ± 0.07[c]	1.19 ± 0.10[c]	14.95 ± 0.93[c]	31.45 ± 3.84[d]
SPC-pH 11	3.53 ± 0.36[b]	2.69 ± 0.22[a]	96.66 ± 1.58 [a]	44.41 ± 1.19[b]
SPC-salt	2.32 ± 0.25[c]	2.03 ± 0.19[b]	49.70 ± 7.34[b]	37.86 ± 2.35[c]
SPI	6.06 ± 0.05[a]	2.94 ± 0.05[a]	5.95 ± 0.43[c]	63.58 ± 1.61[a]

[1] Values are given as mean ± SD from triplicate determination

[a-d] In a column, mean value followed by the same superscript are not significantly different at $p>0.05$ (DMRT)

Fat absorption capacity (FAC) of SPC-salt, SPC-pH 9, SPC-pH 11 and soy protein isolate (SPI) are presented in Table 3. SPC-pH 11 (2.7 g of oil/g of protein) had significantly ($p< 0.05$) higher FAC than SPC-salt (2.0 g of oil/g of protein) and SPC-pH 9 (1.2 g of oil/g of protein), but was similar to SPI (2.9 g of oil/g of protein). FAC of sesame protein concentrates (SPC) from the study were also similar to that reported by Khalid, *et al.* [10] (1.5 ml oil / g protein). FAC of SPC was higher than casein (0.9 g oil/g protein) and was similar to buckwheat protein (2.9 g oil/g protein) and soy protein isolate (2.6 g oil/g protein) [13]. FAC is attributed to the physical entrapment of oil and to the number of nonpolar side chains on proteins that bind hydrocarbon chains on the fatty acids [16]. The difference between FAC of different proteins could be related to the variation in amino acid compositions and several parameters such as hydrophobicity, degree of denaturation and the size and flexibility of the protein.

Emulsifying properties

The emulsifying properties of SPC-salt, SPC-pH 9 and SPC-pH 11 were evaluated in comparison with that of soy protein isolate (SPI). The emulsifying activity index (EAI) of SPC-pH 11 was significantly higher ($p < 0.05$) than those of SPC-salt, SPC-pH 9 and SPI (Table 3). SPC-pH 11 exhibited an increase in EAI as the extraction pH 11 was better than pH 9 and salt. This result indicated that differences in extraction methods and conditions affect emulsifying properties of sesame proteins. All SPCs were also better in EAI than SPI. Previous reports have shown that sesame protein isolate exhibited superior emulsifying properties to soy protein isolate [9, 6]. Normally, EAI is a measure of the ability of the protein to aid the dispersion of the oil phase and to quickly provide sufficient coating of the interfacial area to avoid immediate coalescence [17].

Emulsion stability is a property very often evaluated in relation to time and is related to the droplet size, wherein the smaller the size the greater the stability. The emulsion stability index (ESI) of SPC-pH 11 (44.4 min) exhibited higher indices than those of SPC-salt (37.9 min) and SPC-pH 9 (31.5 min), but were lower than those of SPI (63.6 min) (Table 3). These results suggest that while the SPI may not form an emulsion readily, the stability of the emulsion after its formation is relatively higher. Stability of the protein film formed at the interface of the emulsion is dependent on the interactions of the proteins in oil and aqueous phases [18]. Besides, the various factors, including pH, droplet size, net charge, interfacial tension, viscosity and protein conformation, could affect the values of ES [19].

Foaming properties

The foaming properties (foaming capacity and foaming stability) of SPC-salt, SPC-pH 9 and SPC-pH 11 were compared with SPI (Figures 4 and 5). SPC-salt exhibited higher foaming capacity and stability than SPC-pH 9 and pH 11. When compared with SPI, foaming capacity and stability of all SPCs were lower than those of SPI. Basically, the function of foam is related to the rate of decrease of surface tension of the air/water interface caused by absorption of protein molecules [20]. Graham and Phillips [21] linked good foamability with flexible protein molecules, which reduces surface tension. Low foamability on the other hand can be related to highly ordered globular proteins, which resist surface denaturation. The basic requirements of proteins as good foaming agents are the ability to (i) adsorb rapidly at air-water interface during bubbling, (ii) undergo rapid conformational change and rearrangement at the interface and (iii) form a cohesive viscoelastic film via intermolecular interactions. The first two factors are essential for better foamability whereas the third is important for the stability of the foam. The foaming properties of proteins are influenced by sources of protein, methods and thermal parameters of processing, including protein isolation, temperature, pH, protein concentration, mixing time, method of foaming [20].

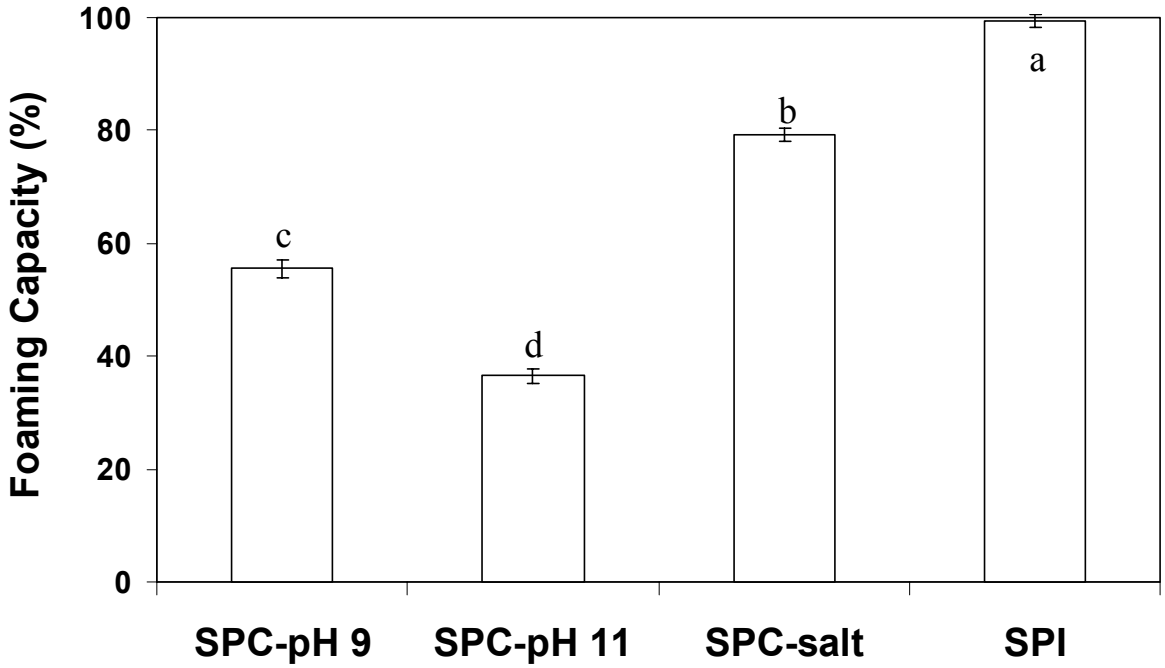

Figure 4. Foaming capacity of sesame protein concentrates by alkali extraction at pH 9 and pH 11 (SPC-pH9 and SPC-pH11) and salt extraction (SPC-salt) in comparison with soy protein isolate (SPI).

DMRT (p<0.05) values are presented as a bar. Columns with different letters are significantly different (p<0.05).

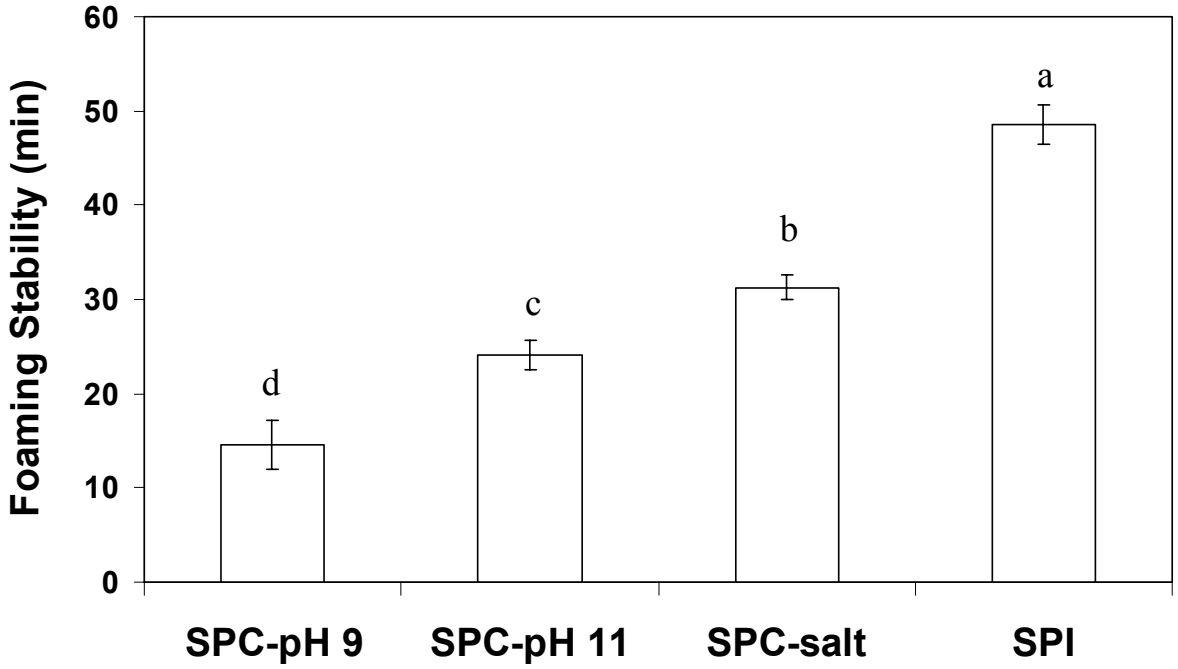

Figure 5. Foaming stability of sesame protein concentrates by alkali extraction at pH 9 and pH 11 (SPC-pH9 and SPC-pH11) and salt extraction (SPC-salt) in comparison with soy protein isolate (SPI).
DMRT (p<0.05) values are presented as a bar. Columns with different letters are significantly different (p<0.05).

Conclusions

Sesame protein concentrates are good sources of protein (75.49-83.25%).

The study of sesame protein concentrates shows that solubility and EAI of the sesame protein concentrates were higher than those of soy protein isolate, while ESI, foaming properties, WHC and FAC of sesame protein concentrates were lower than those of soy protein isolate. Therefore, these proteins may be used as a food ingredient to substitute for SPI, where solubility and emulsifying properties are needed.

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References

1. Office of Agricultural Economics. (2008). Agricultural Statistics of Thailand 2006. Bangkok, Ministry of Agriculture and Co-operatives.

2. Elleuch, M., Besbes, S., Roiseux, O., Blecker, C. and Attia, H. (2007). Quality characteristics of sesame seeds and by-products. **Food Chemistry**, 103 (2), 641-650.

3. Gandhi, A.P. and Srivastava, J. (2007). Studies on the production of protein isolates from defatted sesame seed (*Sesamum indicum*) flour and their nutritional profile. **ASEAN Food Journal**, 14 (3), 175-180.

4. Inyang, U.E. and Iduh, A.O. (1996). Influence of pH and salt concentration on protein solubility, emulsifying and foaming properties of sesame protein concentrate. **Journal of the American Oil Chemists' Society***,* 73(12), 1663-1667.

5. Rivas, N., Dench, J.E. and Caygill, J.C. (1981). Nitrogen extractability of sesame (*Sesamum indicum* L.) seed and the preparation of two protein isolates. **Journal of the Science of Food and Agriculture,** 32 (6), 565-571.

6. Kanu, P.J., Kerui, Z., Ming, Z.H., Haifeng, Q., Kanu, J. and Kexue, Z. (2007). Sesame protein 11: Functional properties of sesame (*Sesamum indicum* L.) protein isolate as influenced by pH, temperature, time, and ratio of flour to water during its production. **Asian Journal of Biochemistry**, *2*(5), 289-301.

7. AOAC (1999). Official Methods of Analysis. (16th ed.). Washington, DC: Association of Official Analytical Chemists.

8. Robinson, H.W. and Hodgen, C.G. (1940). The biuret reaction in the determination of serum protein I. a study of the condition necessary for the production of the stable colour which bears a quantitative relationship to the protein concentration. **Journal of Biological Chemistry.** 135: 707-725.

9. Lopez, G., Flores, I., Galvez, A., Quirasco, M. and Farres, A. (2003). Development of a liquid nutritional supplement using a *Sesamum indicum L.* protein isolate. **LWT-Food Science and Technology,** 36 (1), 64-74.

10. Khalid, E.K., Babiker, E.E. and El Tinay, A.H. (2003). Solubility and functional properties of sesame seed proteins as influenced by pH and/or salt concentration. **Food Chemistry**, 82 (3), 361-366.

11. Vojdani, F. (1996). Solubility. In M. G.M.Hall, Methods of Testing Protein Functionality, pp. 11-60, London: Blackie Academic & Professional.

12. Cheftel, J.L., CuQ, J-L. and Lorient, D. (1985). Amino acids, peptides and proteins. In O.R. Fennema, Food Chemistry, (2nd ed.) (pp. 272-274). New York: Marcel Dekker.

13. Tomotake, H., Shimaoka, I., Kayashita, J., Nakajoh, M. and Kato, N. (2002). Physicochemical and functional properties of buckwheat protein product. **Journal of Agricultural and Food Chemistry**, 50 (7), 2125-2129.

14. Chandi, G.K. and Sogi, D.S. (2007). Functional properties of rice bran protein concentrates. **Journal of Food Engineering**, 79 (2), 529-597.

15. Aletor, O, Oshodi, A.A. and Ipinmoroti, K. (2002). Chemical composition of common leafy vegetables and functional properties of their leaf protein concentrates. **Food Chemistry**, 78 (1), 63–68.

16. Al-Kahtani, H.A. and Abou-Arab, A.A. (1993). Comparison of physical, chemical and functional properties of *Moringa peregrina* (Al-Yassar or Al-Ban) and soybean proteins. **Cereal Chemistry***,* 70 (6), 619-626.

17. Dagorn-Scaviner, C., Gueguen, J. and Lefebvre, J. (1987). Emulsifying properties of pea globulins as related to their adsorption behaviors. **Journal of Food Science**, *52* (2), 335-341.

18. Damodaran, S. (1996). Amino acids, peptides and protein. In O.R. Fennema, **Food Chemistry**, (3 rd ed.) (pp. 417). New York: Marcel Dekker.

19. Hung, S.C. and Zayas, J.F. (1991). Emulsifying capacity and emulsion stability of milk proteins and corn germ protein flour. **Journal of Food Science,** 56 (5), 1216-1223.

20. Sathe, S.K, Deshpande, S.S. and Salunkhe, D.K. (1982). Functional properties of winged bean (*Psophocarpus tetragonolobus*, L) proteins. **Journal of Food Science,** 47 (2), 503-506.

21. Graham, D.E. and Phillips, M.C. (1976). *Foam*, London: Academic Press.

22. Zayas, J.F. (1997). Functionality of Proteins in Food, London: Springer.