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Peanut protein concentrate: Production and functional properties as affected by processing

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Abstract

Peanut protein concentrate (PPC) was isolated from fermented and unfermented defatted peanut flour by isoelectric precipitation and physical separation procedures. PPC was dried by spray or vacuum drying. PPC powders from each drying technique were evaluated for proximate composition and functional properties (protein solubility, water/oil binding capacity, emulsifying capacity, foaming capacity and viscosity) along with defatted peanut flour and soy protein isolate as references. PPC contained over 85% protein versus 50% protein in the defatted peanut flour used as raw material for PPC production. PPC had a solubility profile similar to that of peanut flour, with minimum solubility observed at pH 3.5–4.5 and maximum solubility at pH 10 and higher. Roasting of peanut reduced all functional properties of defatted peanut flour while fermentation had the reverse effect. The type of drying significantly affected the functional properties of PPC. Spray dried PPCs exhibited better functional properties, particularly emulsifying capacity and foaming capacity, than vacuum oven dried PPC. Spray dried PPCs also showed comparable oil binding and foaming capacity to commercially available soy protein isolate (SPC). At equivalent concentrations and room temperature, PPC suspension exhibited lower viscosity than soy protein isolate (SPI) suspensions. However, upon heating to 90 °C for 30 min, the viscosity of PPC suspension increased sharply. Results obtained from this study suggest that the PPC could be used in food formulations requiring high emulsifying capacity, but would not be suitable for applications requiring high water retention and foaming capacity. PPC could be a good source of protein fortification for a variety of food products for protein deficient consumers in developing countries as well as a functional ingredient for the peanut industry. The production of PPC could also add value to defatted peanut flour, a low value by-product of peanut oil production.

Keywords: Defatted peanut flour; Peanut protein concentrate; Functional properties; Drying methods

1. Introduction

Peanut is an important crop grown in the US and worldwide. In 2005, shelled peanut production in the United States was about 4.49 billion pounds (USDA-NASS, 2005). Most peanuts grown in the US are used for oil production, peanut butter, confections, and snack products (Tate, Chavan, Patil, & Kadam, 1990). Vegetable oil extraction from peanut yields partially defatted peanut flour (DPF). DPF is a protein-rich, inexpensive and underutilized by-product of the peanut industry that offers the same health and dietary benefits of peanut with less fat. DPF contains 47–55% high quality protein with high essential amino acid content (Basha & Pancholy, 1982; USDA-NAL, 2005) and lends itself being used in many food applications (Prinyawiwatkul, Beuchat, & McWatters, 1993). The development of a peanut protein concentrate (PPC) from defatted peanut flour would also provide the food industry with a new high protein food ingredient for product formulation and protein fortification. The latter is critically needed in many developing countries where protein deficiencies remain a major health problem, especially among children.

Functional properties of food proteins are important in food processing and food product formulation. Some of these properties are water/oil binding, emulsification, foam

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formation, viscosity and gelation. These properties are affected by the intrinsic factors of protein such as molecular structure and size, and many environmental factors including the method of protein separation/production, pH, ionic strength, and the presence of other components in the food system. The importance of these properties varies with the type of food products in which the protein concentrate is used. For example, proteins with high oil and water binding are desirable for use in meats, sausages, breads, and cakes, while proteins with high emulsifying and foaming capacity are good for salad dressing, sausages, bologna, soups, confectionery, frozen desserts and cakes (Ahmedna, Prinyawiwatkul, & Rao, 1999).

Functional properties of protein are influenced by many factors. For end users, pH, temperature and ionic strength of the food system are important factors to consider. For producers, methods and conditions of protein extraction, as well as downstream processing of extracted proteins such as purification and drying are the factors need to be addressed. Methods used to develop plant protein isolate/concentrate include isoelectric precipitation, alcohol precipitation and hot water extraction. Among plant proteins, the functional properties of soy protein are the most extensively studied. Studies of Hutton and Campbell (1977a, 1977b) and Kinsella (1979) illustrated the effects of temperature, pH and ionic strength on the functional properties of soy protein isolate/concentrate. Recently, functional properties of soy protein fractions, chemical and biochemical modified soy protein were reported. For instance, Jung, Murphy, and Johnson (2005) reported that low degree hydrolysis (2–4%) by endo-protease treatment of soy protein resulted in enhanced functional properties of soy flour. Combination of thermal treatment through partial deamination with mild hydrolysis of protein was reported to increase the solubility of soy protein, thus enhanced the solubility depended functional properties, such as emulsifying and foaming capacity (Matsudomi, Sasaki, Kato, & Kobayashi, 1985). Similar process was also found to enhance the solubility and other functional properties of wheat protein isolate (Ahmedna et al., 1999). Functional properties of many other plant protein concentrates/isolates produced from peas and beans were also studied by a number of investigators (Fuhrmeister & Meuser, 2003; Lawal, 2004; Makri, Papalamprou, & Doxastakis, 2005; Sathe & Salunkhe, 1981).

Functional properties of peanut protein have been the subject of limited studies that focused mainly on peanut flour (Beuchat, 1977; Prinyawiwatkul et al., 1993). Prior to these studies, a comprehensive review by McWattes and Cherry (1982) summarized previous research on the functional properties of peanut flour and peanut protein up to 1981. However, limited information is available in the literature on the development and functionality of peanut protein concentrate (PPC) as affected by processing. Therefore, the objectives of this study were to (1) develop a protein concentrate from defatted peanut flour and (2) determine the functional properties of the peanut flour and protein concentrate as indicators of its potential use by the food industry, and (3) evaluate the effects of processing methods on the functionality of peanut protein concentrates.

2. Materials and methods

2.1. Materials

Defatted roasted peanut flour was purchased from Golden Peanut Company (Apalachia, GA). Partially defatted raw peanut flour was prepared in our lab using a Carver hydraulic press (Carver Inc., Wabsh, IN). Fermented peanut flour was produced in our lab following the procedure described in Section 2.2. All chemicals and reagents were analytical grade compounds purchased from Fisher Scientific (Atlanta, GA).

2.2. Fermentation of peanut flour

Fermented peanut flour was prepared by mixing peanut flour with 5% corn starch, then hydrating the mixture to about 80% moisture. Moist peanut flour was autoclaved at 105 °C for 10 min to inactivate microorganisms initially present in the flour and utensil used. After cooling to 35 °C, the hydrated flour was inoculated with *Rhizopus oligsporus* at a ratio of 1:250 (v/w), and spread in 2-cm layer in a sterilized tray. Trays were covered with perforated aluminum foil and incubated at 37 °C for 24 h. Fermented flour was dried at 70 °C in vacuum oven for 16 h.

2.3. Determination of functional properties of peanut flours

Functional properties evaluated were protein solubility, water holding capacity (WHC), oil binding capacity (OBC), emulsifying capacity (EC), and foaming capacity.

2.3.1. Protein solubility

Defatted peanut flour (fermented or unfermented) was mixed with water in the ratio of 1/20 (w/v), and pH of the mixture was adjusted to 2.0–10.0 with 1.0 N sodium hydroxide (NaOH) and HCl. The peanut flour suspension was let to stir at room temperature for 1 h, and then centrifuged at 3000 g for 15 min. Protein concentration in each supernatant (soluble protein) was determined by a Leco Truspec Nitrogen Analyzer (Leco Corporation, St. Joseph, MI) using 6.25 as conversion factor. The soluble protein content was calculated as gram soluble protein per 100 g flour based on the weight of flour used and supernatant obtained after centrifugation.

2.3.2. Water holding capacities

Water holding capacity was determined using the method outlined by Beuchat (1977). One gram of peanut flour or protein concentrate was weighed into a preweighed 15-mL centrifuge tubes. For each sample, 10 ml of distilled water was added and mixed using a Fisher Gene II vortex at the highest speed for 2 min. After the mixture

was thoroughly wetted, samples were allowed to stand at room temperature for 30 min, then centrifuged (Eppendorf Centrifuge 5810R) at 3000 g for 20 min. The supernatant was decanted and the centrifuge tube containing sediment was weighed. Water holding capacity (grams of water per gram of protein) was calculated as $WHC = (W_2 - W_1)/W_0$, where W_0 is the weight of the dry sample (g), W_1 is the weight of the tube plus the dry sample (g), and W_2 is the weight of the tube plus the sediment (g). Triplicate samples were analyzed for each protein concentrate.

2.3.3. Oil binding capacities

Oil binding capacity was determined using the method of Chakraborty (1986). One gram (W_0) of protein was weighed into pre-weighed 15-mL centrifuge tubes and thoroughly mixed with 10 mL (V_1) of vegetable oil (Wesson vegetable oil) using a Vortex mixer. Samples were allowed to stand for 30 min. The protein–oil mixture was centrifuged at 3000 g (Eppendorf Centrifuge 5810R) for 20 min. Immediately after centrifugation, the supernatant was carefully poured into a 10 ml graduated cylinder, and the volume was recorded (V_2). Fat absorption capacity (milliliter of oil per gram of protein) was calculated as $FAC = (V_1 - V_2)/W_0$. Triplicate samples were analyzed for each flour/protein concentrate.

2.3.4. Emulsifying capacity

Emulsifying capacity (EC) and emulsifying stability (ES) were determined in triplicate according to the method described by Sathe and Salunkhe (1981) with modifications. Two grams of each flour/protein type were mixed with 200 mL of distilled water for 2 min using an Osterizer bender at high speed before addition of 200 mL of vegetable oil containing Red-O-dye additional oil was added slowly under continuous blending. Blending was stopped every 2 min to check for emulsion breakage. When a clear emulsion breakage was observed, the total volume of oil added to was recorded and used to calculate EC as volume (mL) of oil emulsified per gram of flour.

2.3.5. Foaming capacity and stability

Foaming capacity (FC) was determined in triplicate using the method described by Makri et al. (2005). Concentrations of 1% flour were prepared in de-ionized water and adjusted to pH 7.4 with 1.0 N NaCl and 1.0 N HCl. A volume of 100 ml (V_I) of peanut protein concentrate suspension was blended for 3 min using a high-speed blender, poured into a 250 ml graduated cylinder, and the volume of foam (V_F) was immediately recorded. FC was calculated using the following equation: $FC = V_F/V_I$.

2.4. Production of peanut protein isolate/concentrate

2.4.1. Isolation of peanut protein

Un-fermented or fermented flour was used as starting materials to develop peanut protein concentrate using isoelectric precipitation and centrifugation separation.

Protein recovery tests at different water/flour ratio were conducted to determine the conditions for optimum protein recovery. Peanut flour was mixed with water at flour to water ratios of 1/100, 1/50, 1/20, and 1/10. The pH of each suspension was adjusted to pH 10, based on the solubility profile of protein in peanut flour (Section 2.3), using 1.0 N NaOH and 1.0 N, HCl, and stirred for 1 h at room temperature. Suspensions were centrifuged and protein concentration in each supernatant was determined by a Leco Truspec Nitrogen Analyzer (Leco Corporation, St. Joseph, MI) using 6.25 as conversion factor. Protein concentration was expressed as percent of extracted flour.

The optimum peanut protein recovery was achieved at flour/water ratio of 1/20 and a solubilization pH of 10. These conditions were used in subsequent production of peanut protein concentrates. To produce test PPC, defatted peanut flour (fermented or unfermented) was mixed with water in the ratio of 1/20 (w/v), and pH of the mixture was adjusted to 10.0 with 1.0 N sodium hydroxide (NaOH). The peanut flour suspension was let to stir at room temperature for 1 h, then centrifuged at 3000 g for 15 min. The supernatant was collected and adjusted to pH 4.5 (the isoelectric pH as determined in Section 2.3) with 1.0 N hydrochloric acid (HCl). The suspension was centrifuged at 3000 g for 15 min. The supernatant was discarded and the precipitate was dried using one of two drying methods.

2.4.2. Drying methods of peanut protein isolate/concentrate

The precipitate obtained from above procedure was either dried by vacuum oven or spray dryer. For vacuum oven drying, precipitate was directly dried overnight at 70 °C, and ground into powder with pH adjustment upon use/rehydration. Spray drying involved re-suspension in water in the ratio of 1/10 followed by pH adjustment to pH 7.4 with NaOH solution (1.0 N). After pH adjustment, the suspension was filtered through Fisher P8 filter paper and dried using a Buchi Mini spray dryer B-191 (Buchi Laboratory, Flawil, Switzerland). The dry PPC powder from both drying methods was stored in refrigerator until use in functionality tests.

2.5. Determination of functional properties of peanut protein concentrates

Methods described under Section 2.2 were used to determine the functional properties (WHC, OBC, EC and FC) of peanut protein concentrates. However, the amount of spray dried PPC was reduced due to the higher protein content and enhanced functionalities. Functional properties of soy protein isolate (91% protein, bulkfoods.com) were determined using same methodology and used as reference. In addition to the above functional properties, viscosity of PPC gels was also determined as described bellow.

2.5.1. Viscosity of peanut protein paste/gel

Gel strength was determined in triplicate according to the procedure described by Chakraborty (1986). Protein

suspensions containing 7.5, 10, and 12.5% peanut protein concentrates or commercial soy protein isolate (91% protein, bulkfoods.com) were prepared, and pH of suspensions was adjusted to 7.4 with 1.0 N NaOH and HCl. Viscosities of these protein suspensions were measured by a programmable Brookfield DV-II + Viscometer (Brookfield, Middleboro, MA) at room temperature (23 °C). Suspensions were heated to 90 °C in a shaking water bath and kept for 30 min, then cooled to room temperature without stirring. Gel viscosity (centipoises) was determined using a Brookfield VD-II + Viscometer at different shear rates (10, 30 and 50 rpm) at room temperature (23 °C).

2.6. Proximate composition analysis

Total protein content of peanut flour and peanut protein concentrates was evaluated using a LECO nitrogen analyzer and a conversion factor of 6.25. Fat, moisture and ash were determined using standard AOAC methods 932.06, 925.09 and 923.03, respectively (AOAC, 1990).

2.7. Data analysis

Data were analyzed by analysis of variance using SAS (SAS, 2002). Mean differences were judged at the 5% significance level. Tukey test was used for pair-wise comparison of outcome variable mean.

3. Results and discussions

3.1. Effects of processing methods on functional properties of peanut flour

3.1.1. Peanut protein solubility

Protein solubility is the most important functional property because it influences other functional properties. Roasting, a heat processing method has both desirable and undesirable effects on peanuts and peanut protein. Heating destroys antimetabolites such as trypsin and amylase inhibitors in legumes, thus improving the bioavailability or digestibility of the protein (Snyder & Kwon, 1987). Roasting also adds pleasant flavor/aroma to peanuts and makes peanut palatable. However, roasting may significantly affect the functionality of peanut flour because of partial denaturation of protein. Roasting of peanuts significantly decreased protein solubility in peanut flour in the pH range 3.5–10.0 compared to that in raw peanut flour as shown in Fig. 1. This is in agreement with the findings of Cherry and McWatters (1975) who reported that heating full fat peanut seed in water at 100–120 °C for 15 min decreased protein solubility. This decrease can be explained by the effect of heating which increases surface hydrophobicity of protein due to unfolding of molecules upon heat and molecular size through hydrophobic interactions and disulfide formation.

The effect of fermentation on the solubility of raw peanut protein differs from roasted peanut protein. Fig. 2 shows that fermentation significantly increased protein solubility in defatted roasted peanut flour across the pH range tested (pH 3.0–10.0), but decreased protein solubility of raw peanut flour at higher pH (pH 6–10). This is in agreement with the finding of Prinyawiwatkul et al. (1993) who also reported an increase of protein solubility of roasted peanut flour following fermentation.

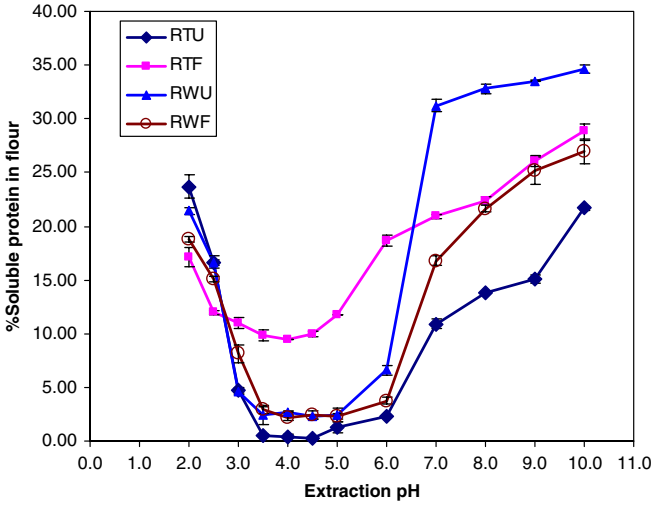

Fig. 1. Effects of pH on peanut protein solubility and extractability at flour/water ratio of 1/20. Percentage of soluble protein was calculated at dry flour basis. (RWU-raw unfermented peanut flour, RWF-raw fermented peanut flour, RTU-roasted unfermented peanut flour, RTF-roasted fermented peanut flour).

The pH had a significant effect on the solubility of peanut protein. As shown in Fig. 1, the minimum protein solubility tested was observed at pH 3.5–4.5 and maximum solubility at pH 10 or higher. The extraction of peanut protein was, therefore, conducted at pH 10 as to ensure maximum yield. The use of pHs higher than 10 was not desirable because of undesirable changes such as protein denaturation discoloration which could affect the functionality and sensory quality of PPC. Based on the data in Fig. 1, pH 4.0 was used to separate protein from the supernatant through isoelectric precipitation since peanut proteins seem to be least soluble at this pH. The solubility pattern of peanut protein was found similar to that of soy protein (Shen, 1981), suggesting possible similarity in functional properties and protein composition of these two plant proteins. In fact, the amino acid profiles of peanut protein and soy protein are comparable with exception of lower lysine level in peanut (USDA-NAL, 2005).

3.1.2. Water/oil holding capacity

Interactions of water and oil with proteins are very important in food systems because of their effects on the flavor and texture of foods. Intrinsic factors affecting water binding capacity of food proteins include amino acid composition, protein conformation, surface polarity/hydrophobicity (Barbut, 1999). However, food processing methods have important impacts on the protein conformation and hydrophobicity. Data obtained in this study show

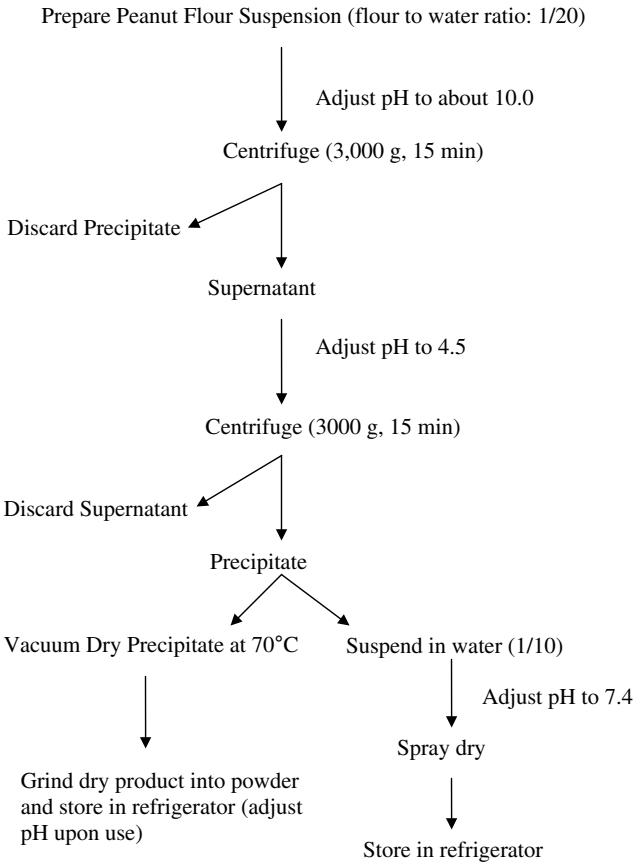

Fig. 2. Chart showing major steps of the protein concentrate production.

that roasting reduced both WHC and OBC of peanut flour while fermentation increased WHC and OBC of both raw and roasted peanut flours (Table 1). During roasting, peanut proteins were likely denatured by high temperature exposing more hydrophobic sites, which explains the reduced water retention of peanut protein. The decreased oil binding capacity could be due to irreversible denaturation caused by roasting at 175 °C which might have destroyed both hydrophilic and hydrophobic groups of peanut proteins, thus reducing both water and oil holding capacity. The effect of fermentation on OBC of partially defatted raw peanut flour was marginally significant ($p = 0.09$), but fungal fermentation significantly enhanced the water and oil retention of roasted peanuts ($p < 0.05$). This is consistent with the results reported by Prinyawiwatkul et al. (1993). Increased WHC and OBC in fermented peanut flour seem to parallel the higher protein solubility and could be explained by proteolytic activity of fungal enzymes which produces soluble oligopeptides.

3.1.3. Emulsifying capacity (EC)

Food emulsions are thermodynamically unstable mixtures of immiscible liquids (water and oil). The formation and stability of emulsion is very important in food systems such as salad dressing. Proteins are composed of charged amino acids, non-charged polar amino acids and nonpolar amino acids, which makes protein a possible emulsifier, the surfactant possessing both hydrophilic and hydrophobic properties and be able to interact with both water and oil in food system. As shown in Table 1 defatted peanut flour was a good emulsifier with EC of 87 mL/g probably due to its high protein content. Roasting did not significantly impact the EC of peanut flour ($p > 0.05$) while fermentation significantly increased EC of raw and roasted DPF by 41 and 96%, respectively ($p < 0.001$). The effect of roasting on the emulsifying capacity of the peanut flour might be balanced by the increase of surface hydrophobicity and the decrease in solubility of peanut proteins. The higher emulsifying capacity of fermented peanut flour might be the result of proteolytic hydrolysis of protein by protease produced by *Rhizopus oligosporus* during fermentation (Nowak & Szebiotko, 1992; Varzakas, 1994). Proteases degrade peanut protein from polypeptides into oligopeptides, thus increasing the protein solubility and exposing more hydrophobic groups to water and oil interface, resulting in increased EC and stable emulsion. The enhanced EC of defatted peanut flour by fungal fermentation observed in this study is in agreement with the results of Prinyawiwatkul et al. (1993).

3.1.4. Foaming capacity (FC)

The formation of foam is analogous to the formation of emulsion. In the case of foam, water molecules surround air droplets, and air is the non-polar phase. Theoretically, the amphipathic character of protein makes them the good foaming agents that work at air–water interface to prevent bubble coalescence. Data in Table 1 suggest that defatted peanut flour is not a good foaming agent, with a FC of only 0.06 ml/ml liquid. Roasting of peanuts reduced the FC by half while fermentation of roasted peanut flour increased the FC by about 3-fold. Therefore, defatted peanut flours may not be suitable in food system that requires foaming such as cake and ice cream.

Table 1
Effect of roasting and fermentation on functional properties of peanut flour

Functional properties (ml/g)	Raw		Roasted	
	Unfermented	Fermented	Unfermented	Fermented
Water binding capacity	1.67 ± 0.29	2.25 ± 0.43	1.00 ± 0.00	1.67 ± 0.29
Oil binding capacity	2.67 ± 0.29	2.33 ± 0.76	1.67 ± 0.29	2.50 ± 0.00
Emulsifying capacity	87.08 ± 6.02	123.33 ± 5.53	87.50 ± 5.00	171.00 ± 1.00
Foaming capacity	0.06 ± 0.006	0.05 ± 0.006	0.03 ± 0.00	0.08 ± 0.006

Each value in the table was the mean of three replications ± standard deviation.

Overall, roasting decreased functionality of peanut flour while fermentation significantly increased all functional properties of both raw and roasted peanut flours. The increased protein solubility and water binding capacity suggests that fungal fermentation of peanut flour modified peanut proteins through diverse mechanisms including hydrolytic breakdown of large protein molecules resulting in better protein functionality.

3.2. Proximate composition of defatted peanut flours and peanut protein concentrates

The proximate composition of peanut protein concentrates was influenced by the type of peanut flour used. As shown in Table 2 that PPC developed from roasted peanut flour had higher protein (85.67%), lower fat content (2.7%), and less moisture than that obtained from raw peanut flour (Table 2). The lower protein content (77%) of protein concentrate developed from raw peanut flour was probably due to higher fat content of raw flour (17% versus 12% in the case of roasted peanut flour). Such a high fat content could have reduced the efficiency of protein extraction from raw peanut flour, due to the formation of emulsion in conjunction with protein during extraction, and resulted in higher fat and lower protein content in the final product as shown in Table 2. In fact, peanut protein isolate which has protein content higher than 90% was only produced from peanut flour after extensive defatting using hexane (McWattes & Cherry, 1982). The ash contents in both protein concentrates were about the same but much lower than those in the flour. This is expected since most minerals would be discarded in the supernatant after protein precipitation.

3.3. Effect of flour to water ratios and pH on peanut protein recovery

Peanut protein concentrate was produced by the procedure showing in Fig. 2. According to this flow chart, the recovery of peanut protein is determined by the solubilization of protein in extraction medium and precipitation of extracted protein from supernatant. Therefore, it is important to establish the optimum condition to yield the maximal protein recovery. As discussed in Section 3.1, peanut protein had highest and lowest solubility at pH 10 and 4.0, respectively. Thus PPC was produced by separation of peanut protein at a solubilization pH of 10.0 and a precipitate pH of 4.0 followed by drying. At these conditions, the flour to water ratio used in protein extraction also significantly affected the efficiency of protein recovery with maximum recovery achieved at flour to water ratio of 1/20 (Fig. 3). The 1/50 ratio yielded about the same amount of protein as the 1/20 ratio; however, excess water removal could make the use of 1/50 ratio less cost effective. Therefore, the 1/20 ratio was used for peanut protein extraction during development of PPC. Overall, data in Fig. 2 show that the highest recovery was observed in fermented peanut flour extracted at optimum flour to water ratio of 1/20.

3.4. Effects of drying method on functionality of peanut protein concentrate

The type of drying methods showed significant effects on the functionality of protein concentrate (Table 3). Vacuum dried PPC had lower WHC, OBC, and FC than the corresponding peanut flour and spray dried concentrates. Spray drying improved all functional properties of PPC, particularly, EC and FC. For instance, spray drying increased EC of PPCs from raw and roasted peanut flours by 57% and 206.3%, respectively. A similar trend was observed for

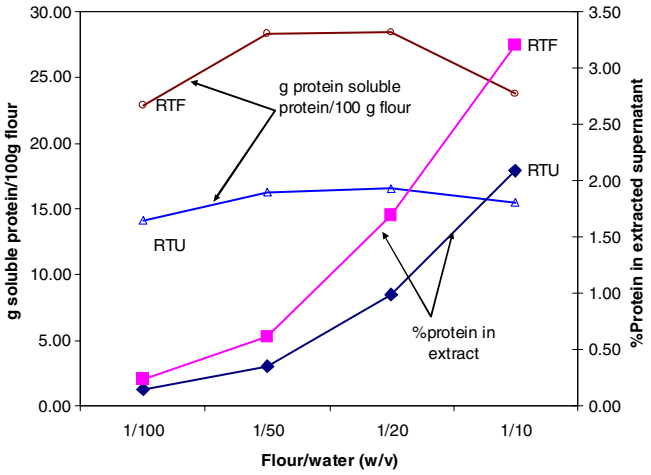

Fig. 3. Effects of flour/water ratio on the solubility and recovery of peanut protein at pH 10.0. (RTU-roasted unfermented peanut flour, RTF-roasted fermented peanut flour).

Table 2
Proximate composition of raw and roasted peanut flour and corresponding protein concentrates

Components (%)	Raw peanuts		Roasted peanuts	
	Defatted flour	Protein concentrate	Defatted flour	Protein concentrate
Protein[a]	52.73 ± 0.12	77.82 ± 0.59	54.58 ± 0.34	85.67 ± 0.36
Fat	17.00 ± 1.955	13.00 ± 0.849	12.15 ± 2.64	2.99 ± 0.01
Moisture	4.72 ± 0.064	4.62 ± 0.081	5.84 ± 0.046	2.73 ± 0.138
Ash (%)	4.85 ± 0.16	0.76 ± 0.19	4.07 ± 0.38	0.77 ± 0.20
Others	19.38	1.86	22.30 ± 1.04	0.55 ± 0.38

Each value in the table represents the mean of three replications ± standard deviation.
[a] A conversion factor of 6.25 was used in calculation of protein content.

Table 3
Effects of processing methods on functional properties of peanut protein concentrates

Functional properties	Raw peanut protein concentrates				Roasted peanut protein concentrates				Control
	Unfermented		Fermented		Unfermented		Fermented		SPI
	Vacuum	Spray	Vacuum	Spray	Vacuum	Spray	Vacuum	Spray	Spray
WHO (ml/g)	1.11 ± 0.05	1.63 ± 0.05	0.70 ± 0.04	1.56 ± 0.02	0.83 ± 0.07	1.33 ± 0.28	0.75 ± 0.00	2.22 ± 0.07	5.29 ± 0.12
OBC (ml/g)	0.90 ± 0.03	1.58 ± 0.02	1.33 ± 0.29	1.43 ± 0.15	1.00 ± 0.25	2.08 ± 0.38	1.33 ± 0.52	2.14 ± 0.19	1.48 ± 0.05
EC (ml/g)	87.50 ± 5.00	137.50 ± 1.92	94.25 ± 1.15	197.46 ± 4.41	90.00 ± 5.00	275.67 ± 4.04	89.58 ± 1.44	279.58 ± 4.66	544.67 ± 5.03
FC (ml/ml)	0.02 ± 0.00	0.10 ± 0.00	0.03 ± 0.00	0.17 ± 0.01	0.02 ± 0.00	0.09 ± 0.01	na	0.25 ± 0.01	0.17 ± 0.01

Each value in the table was the mean of three replications ± standard deviation.

the PPCs from fermented raw and roasted peanut flour where spray drying yielded concentrates with better functional properties.

The better functionalities of spray dried peanut protein concentrates is attributed to the faster/instant drying which likely led to less protein denaturation, and smaller particle size compared to overnight vacuum oven drying. This observation is supported by literature data which report that partial heat denaturation of proteins improves their surface activity (Dickinson & Hong, 1994; Zhu & Damodaran, 1994) while excessive heat denaturation might reduce the emulsifying capacity by rendering the protein insoluble (Voutsina, Cheung, & Nakai, 1983). Ahmed and Schmidt (1979) also reported that spray- and freeze–dried peanut protein isolates has substantially higher solubility values than drum-dried isolate. Spray drying is a very fast drying during which protein molecules are only subjected to a few seconds of heating, which minimizes their denaturation. In contrast, protein molecules were subjected to excessive denaturation during vacuum oven drying. Despite the low cost of oven drying, it may not be suitable for the production of highly functional peanut protein concentrate. That is, why protein concentrates/isolates available in the market are usually made via spray drying to provide ingredients for a variety of food formulations requiring protein for functionality or protein fortification. Compared to commercially available soy protein isolate (SPI), spray dried PPCs had slightly lower WHO and EC than SPI but spray dried PPCs made from fermented peanut flour had comparable or better OBC and FC than commercial SPI (Table 3).

3.4.1. Viscosity and gel strength of peanut protein suspension

Viscosity is an important property of foods that affects mouth feel, the texture of fluid such as beverage and processing such as pumping, extrusion and drying. If the concentration is high enough, the protein suspension can form gel upon heating followed by cooling. Table 4 compares the viscosities of peanut protein concentrate suspensions (PPC from roasted peanut flour) and soy protein isolate before and after heating. As shown in Table 4, viscosities of PPC suspensions before heating were lower than that of SPI at all concentrations and shear rates. PPC did not absorb much water upon suspension in cold water, resulting in lower viscosities. This can be explained by the generally low water binding capacity of PPC as shown in Table 3. SPI, on the other hand absorbed large amount of water upon hydration and swelled producing a very viscous paste and higher viscosity reading even before heating.

Upon heating to 90 °C and cooling to room temperature, gelation was observed in the suspensions containing 10% or higher PPC and SPI. Suspension of 7.5% PPC became solution after heating, 10% PPC suspension produced soft gel while 12.5% PPC suspension turned into a firm gel. Viscosities of PPC sol–gels at 10 rpm increased from 16, 23 and 74 cp before heating to 320, 1150, and 31813 cp after heating, respectively. The reverse was observed for SPI where viscosity of heat treated SPI gels decreased to 260, 1240 and 14,797 cp from 340, 6200 and 21,455 cp, respectively. Viscosities of the gels formed from PPC and SPI decreased with increasing shearing rate (rpm) but maintained the same trend discussed above. Therefore, PPC gel is ''shearing thinning'', which could be due to the shear-induced breakdown of the gel structure. These results indicate that the viscosity of PPC suspension is greatly affected by temperature. Protein gels are important in food products such as sausage and yogurt. Lower viscosity of protein suspension before heating is desirable during pumping and piping, and higher viscosity and gel formation after heating is desirable for the thickening of soup, and production of sausage and meat analog. PPC exhibited these desirable rheological properties making it a good candidate for many food formulations that require heat induced gelling.

4. Conclusion

The ability of peanut flours and peanut protein concentrate to be functional is primarily due to their soluble protein contents. Proteins with high oil and water binding are desirable for use in meats, sausages, breads, and cakes while proteins with high emulsifying capacity are good for sausages, bologna, soups and salad dressing. Fermented peanut flour and the derived protein concentrate showed better functional properties, particularly, water holding and emulsifying capacity, than the unfermented flour and protein concentrate. Spray dried PPC developed from roasted peanut flour had better oil holding and emulsifying capacity than the flour itself and would be suitable for use in products like meats and sausage. The extremely high emulsifying capacity of this PPC makes it also a good candidate for food formulations requiring high emulsifying

Table 4
Viscosity comparison between suspensions of soy protein isolate (SPI, 91% protein) and peanut protein concentrate (PPC, 87% protein) before and after heating

Protein concentration						
Shear rate (rpm)	7.5%		10.0%		12.5%	
	SPI	PPC	SPI	PPC	SPI	PPC
10	260 ± 35 (340 ± 35)[a]	320 ± 35 (16.0 ± 1.7)	1240 ± 151 (6200 ± 229)	1150 ± 125 (23.0 ± 1.7)	14,797 ± 916 (21,455 ± 1506)	31,813 ± 3212 (74.0 ± 1.7)
30	120 ± 0 (277 ± 11)	193 ± 12 (8.7 ± 0.6)	500 ± 35 (2200 ± 40)	7777 ± 179 (13.0 + 1.0)	6712 ± 605 (8678 ± 144)	10,991 ± 865 (55.7 ± 0.6)
50	64 ± 14 (22 ± 7)	136 ± 7.0 (9.0 ± 0.0)	324 ± 48 (1376 ± 109)	5463 ± 184 (14.8 ± 0.3)	5431 ± 482 (6171 ± 88)	7087 ± 299 (49.8 ± 0.6)

Each value in the table was the mean of three replications ± standard deviation.
[a] Values in parentheses are initial viscosity reading prior to heating.

capacities such as salad dressing and creamy soup. The low viscosity of PPC suspension at room temperature and higher viscosity upon heating make PPC a desirable thickener for high protein soups. In addition, the fact that PPC with better functionality could be developed from roasted defatted peanut flour is an important advantage to the peanut oil industry because the roasted defatted peanut flour is an inexpensive by-product of peanut oil production. Thus, peanut protein isolates and concentrates have the potential to add value to the peanut industry and provide food processor with affordable source of plant proteins with unique flavor and functional characteristics.

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