Kinetic studies on palm heart protein solubility and investigation of physicochemical, functional and thermal properties of palm heart protein isolate

Abdollah Hematian Sourki¹ · Mahsa Rahmanian²

Revised: 12 January 2019 / Accepted: 31 January 2019 / Published online: 18 February 2019
© Association of Food Scientists & Technologists (India) 2019

Abstract The chemical composition of palm heart (cultivar Piarom) and solubility kinetics of its protein was investigated under different salt concentrations and pHs. Palm heart protein isolate (PHPI) was prepared using alkaline extraction and acidic precipitation and its functional properties (emulsifying properties and emulsion stability, foam capacity, and water holding and fat absorption capacity) and thermal properties were determined. It was revealed that palm heart had high nutritional value and contains high protein content. By increasing pH up to 3, solubility was decreased and then significantly increased by elevating pH to 9 ($p < 0.05$). Salt addition significantly decreased palm heart protein (PHP) solubility. Considering solubility kinetics, pH 9 and salt concentration of 0.25 M was determined as the best protein extraction condition. Denaturation temperature and enthalpy changes of PHPI were 108.63 °C and 143.1 J/g; suggesting high thermal stability of this product. Regarding its suitable functional, physicochemical and thermal properties, PHP can be considered as an ideal substitution for animal protein sources in the food industry.

Keywords Palm heart · Protein solubility · Protein isolate · Functional properties · Thermal properties

Introduction

Palm heart or Palmito refers to stem cells of date palm obtained from shoots emerging from palm head or main branch covered by broad leaves. It is usually obtained from young trees (4–5 years old). Palm heart is an edible white, cylindrical substance like an onion which contains some rings in middle parts. It is a low acid product with pH ranging from 5 to 7 and high buffering capacity. Investigation of the food value of palm heart cultivar Kabkab has revealed that this product has higher nutritional value than many fruits and vegetables (Movahed et al. 2011). Palm heart of Wild date palm (*Phoenix sylvestris* (L.) Roxb) is a good source of carbohydrates, protein, lipid, energy, vitamins K and C and minerals. Moreover, this 'Wild date palm' cultivar can be used as an ideal substitute in the human diet (Salvi and Katewa 2014).

Use of plant-based proteins in diets has been highly recommended during recent years since it is much cheaper and more abundant than animal proteins. Moreover, this practice reduces consumption of saturated animal fats and hence, prevents chronic diseases such as cardiovascular diseases, Diabetes mellitus, hyperlipidemia, hypertension, cancer and osteoporosis (Singh et al. 2014). Therefore, application of plant proteins as a new alternative and inexpensive source of high quality protein has gained much more attention (Hassan et al. 2010). Plant protein isolates (more than 90% protein) are widely used as functional materials in food systems due to low lipid content and suitable functional properties.

Extraction method has a significant impact on functional properties of plant proteins. Bakhshi Moghadam et al. (2013) compared two extraction methods viz. alkaline and acidic methods for preparing protein isolate of Kabuli chickpea and observed that alkaline method has better

✉ Abdollah Hematian Sourki
a.hematian@jahromu.ac.ir

¹ Department of Food Science and Technology, Faculty of Agriculture, Jahrom University, PO Box: 74135-111, Jahrom, Iran

² Kherad Institute of Higher Education, Bushehr, Iran

performance than acidic extraction regarding extraction efficiency, water and fat absorption capacity. In contrast, foaming, emulsifying and foam and emulsion stability was better in the acidic method. Xu and Diosady (2002) investigated the extraction condition of canola protein isolate and reported that its functional properties depend on pH variation. Rahbari et al. (2013) reported that not only pH, but also salt concentration has a significant impact on the functional properties including solubility of wheat germ protein. One of the advantages of alkaline extraction is that it improved functional properties of the protein. This treatment improves solubility, foaming and emulsifying capacity. High purity (90%) protein isolate can be achieved via alkaline extraction and acidic precipitation in isoelectric point (Garba and Kaur 2014). Isolate preparation by this method results in retention of nutritional value and functional properties of the protein. Functional properties refer to those innate physicochemical characteristics that affect protein behavior during processing, production, storage and preparation and include solubility, water holding and oil absorption capacity, foaming and emulsifying properties (Martínez et al. 2009). These properties are influenced by various factors including protein source, flour/isolate production process and every physicochemical factor such as temperature, salt concentration, pressure, and pH (Liu et al. 2010). Every change in these factors is accompanied by corresponding changes in functional properties of protein such as solubility (Liu et al. 2010). These properties directly affect food texture and its sensory attributes and can be used as a suitable factor in products such as cookies, beverages and meat products (Boye et al. 2010).

Protein configuration is vulnerable to various factors such as temperature that leads to denaturation. The process which causes this change is called denaturation. This change may put a significant impact on functional properties of proteins. Material behavior as a result of increased temperature can be evaluated using DSC technique which provides a curve representing heat flux against time or temperature. Many kinds of researches have been carried out to investigate the thermal stability of plant protein isolates so that denaturation temperatures for protein isolates of soybean, rice bran, Kabuli chickpea and *Phaseolus vulgaris* bean determined (98.95, 83.4, 98.1, 89.55 °C respectively) and corresponding enthalpy changes have been determined (6.59, 0.96, 2.84 and 12.14 J/g respectively) (Kaur and Singh 2007; Liu et al. 2008). Few studies have been conducted on physicochemical properties of palm heart and there has been no research about the extraction and determination of functional properties of palm heart protein isolate (PHPI). Therefore, the present study was conducted aiming at (1) evaluating solubility kinetics of PHP under various conditions, and (2)

investigating physicochemical, functional and thermal properties of PHPI as a new plant-based protein source in food industry.

Materials and methods

Sample preparation

Palm heart (cultivar Piarom) sample was randomly obtained from a palm orchard around Jahrom (Fars province, Iran), cleaned and freeze dried, then it packed in impermeable bags and stored at − 18 °C until beginning of the experiments.

Protein solubility determination

The freeze dried sample was powdered by kitchen miller and its lipid was removed by n-hexane via soxhlet extractor. The solubility of the sample was determined by the method proposed by Martínez et al. (2009) a little modification. For determination of solubility kinetics, palm heart suspensions in distilled water (1:10 w/v) were prepared. The resulting suspensions were mixed at room temperature for 1 h on magnetic hotplate stirrer and their pHs were set at 1, 3, 5, 7, 9 and 11 using 0.5 M HCl and NaOH and left under continuous mixing for 30 min. then, the suspensions were centrifuged at 4 °C and 8000 rpm for 20 min and the resulting supernatants were collected by passing through Double Rings filter paper No. 102. Supernatant was dried using freeze drier and its raw protein content was measured by micro-Kjeldahl method. The protein solubility was determined as the ratio of protein content of supernatant to total the protein content of the sample as represented in Eq. 1:

$$\text{Solubility} = \frac{W_1}{W_2} \times 100 \quad (1)$$

where W_1 stands for protein content of supernatant and W_2 shows protein content of the sample.

For investigating salt concentration impact on solubility, a suspension of palm heart powder was prepared (1:10 w/v) by addition of various salt concentrations (0, 0.25, 0.5, 0.75 and 1 M) the abovementioned procedure was repeated. For investigating the interaction of pH and salt, suspension of palm heart powder (1:10 w/v) was prepared at various salt concentrations (0, 0.25, 0.5, 0.75 M) and for every salt concentration, pHs of 3, 5, 7 and 9 were set and the same procedure was repeated.

Preparation of PHPI

PHPI (Piarom cultivar) was prepared by the method developed by Johnson and Brekke (1983) with some modification using alkaline extraction and acidic precipitation. The suspension of palm heart powder (1:10 w/v) was prepared in a 1 L beaker. pH was set at 9.5 using 0.5 M NaOH and the suspension was mixed under fixed pH for 1 h using magnetic stirrer. Then, the suspension was centrifuged at 4 °C and 10,000 rpm for 15 min. The supernatant was passed through Double Rings filter paper No. 102. The precipitated material was collected and again a suspension (1:15 w/v) was prepared, pH was set at 9.5 and the suspension was mixed for 1 h at room temperature. The suspension was centrifuged at 4 °C and 10,000 rpm for 15 min and the supernatant was passed through Double Rings filter paper No. 102 (this step was repeated to improve extraction efficiency). Supernatant pH was set at 4.5 using 0.5 M HCl; the suspension was mixed for 1 h at room temperature and then was centrifuged at 4 °C and 10,000 rpm for 15 min. The precipitated protein isolate was collected and put on a watch glass. Finally, the protein sediment was washed with distilled water (to remove extra acid) so that pH reached 7; the samples were put in aluminum frames and frozen at -18 °C and, in the next steps, was dried by freeze dryer for investigation of functional properties.

Functional properties of PHPI

Emulsion preparation

Formation, capacity and stability of emulsion against temperature were investigated by the method developed by Papalamprou et al. (2010) with some modifications. In brief, 0.9 g of protein isolate was mixed with 90 g water to achieve a transparent (1%w/w) solution. Oil in water emulsion (10/90 v/v) was prepared by addition of 10 ml of corn oil (density of 0.92 at 25 °C) to 90 ml of isolate solution with pH 7 and simultaneous stirring by a magnetic stirrer. Ten minutes after mixing, the initial emulsion was homogenized using sonicator device at room temperature.

Emulsifying capacity (EC)

Immediately after homogenization, the emulsion was centrifuged at 1100 g for 5 min and EC was calculated by this equation (Eq. 2):

$$EC\% = \frac{V_1}{V_2} \times 100 \quad (2)$$

where V_1 denotes emulsion height after centrifugation and V_2 represents the height of total solution before centrifugation.

Emulsion stability (ES)

Emulsions were put in hot water bath at 80 °C for 30 min and then centrifuged at 1100g for 5 min at room temperature. Emulsion stability was estimated via dividing final volume to initial volume of the emulsion as represented below (Papalamprou et al. 2010):

$$ES\% = \frac{V_1}{V_2} \times 100 \quad (3)$$

where V_1 and V_2 represent emulsion height after and before heating; respectively.

Foaming capacity (FC) and foam stability (FS)

Foaming capacity (FC) and foam stability (FS) was measured by the method developed by Lawal et al. (2005) with some modifications. Exactly, 1 g of the sample was weighed and mixed with 50 ml distilled water for 5 min at speed 2 (high speed). Then it was transferred to 250 ml graded cylinder. Solution volume before and after stirring was measured and FC was estimated by the equation below:

$$FC\% = \frac{V_2 - V_1}{V_1} \times 100 \quad (4)$$

where V_2 and V_1 stand for solution volume after and before stirring.

For measurement of foam stability, the changes of foam volume were recorded at 20, 30 and 60 min intervals. Foam stability after 30 min was assigned as FS.

$$FS\% = \frac{V_2 - V_0}{V_1 - V_0} \times 100 \quad (5)$$

where V_2 denotes solution volume after intended time, V_0 stands for solution volume before stirring and V_1 shows solution volume after stirring.

Water holding capacity (WHC)

WHC was measured by the method proposed by Chandi and Sogi (2007). In brief, 1 g of protein isolate was weighed in pre-weighed centrifuge tube. Then 20 ml water was added and stirred for 10 min. the resulting mixture was centrifuged at 2000 g and 25 °C for 10 min. supernatant was discarded and the tube was put upside down on a filter paper.ube was weighed again and WHC was estimated as represented below:

$$\text{WHC} = \frac{W_2 - W_1}{W_0} \times 100 \quad (6)$$

where W_0 is dry weight of the sample (g), W_1 stands for tube weight plus sample dry weight (g) and W_2 shows tube weight plus sediment weight (g).

Fat absorption capacity (FAC)

Exactly, 1 g of protein isolate was mixed with 10 ml corn oil (density of 0.92 at 25 °C) for 10 min in a pre-weighed centrifuge tube. After centrifugation at 2000g and 25 °C for 15 min, supernatant was discarded, the tube was put upside down on a filter paper for some minutes and weighed again (Chandi and Sogi 2007). FAC was calculated by Eq. 7:

$$\text{FAC} = \frac{W_2 - W_1}{W_0} \times 100 \quad (7)$$

where W_0 represents dry weight of the sample (g), W_1 stands for tube weight plus sample dry weight (g) and W_2 denotes tube weight plus sediment weight (g).

Thermal properties of PHPI

Sample preparation

2 mg of protein isolate was prepared by freeze drying method and 10 µl water was added and the mixture was stored at room temperature for 1 h.

Differential Scanning Calorimetry (DSC) analysis

The prepared sample was put in a small pan and sealed. DSC was calibrated with indium (T_m , onset = 156.6 °C, ΔH = 28.45 J/g) in terms of enthalpy and temperature. A DSC pan containing water (same weight with the sample) was considered as control. The samples were heated from 20 to 120 °C at the rate of 5 °C/min. Glass transition temperature (T_g), denaturation temperature (T_d) and denaturation enthalpy (ΔH) were measured by heating the sample in DSC. T_g was reported by estimating T_g onset and midpoint. ΔH was estimated by calculating area beneath endothermic curve and T_d and T_0 were estimated using STAR system software.

Statistical analysis

In order to investigate the effect of various pHs and salt concentrations on PHP solubility, a completely randomized experiment in the form of factorial arrangement was carried out with two treatments and three replications at various levels of NaCl (0, 0.25, 0.5 and 0.75 M) and pH (3, 5,

7 and 9). Mean comparison was conducted using multiple-range Duncan test ($p < 0.05$). Analysis of variance (ANOVA) was performed using Minitab 18 software and graphs were drawn by Excel 2013 software.

Results and discussion

Chemical composition of palm heart

According to the results, palm heart has high protein content (20.03% d.b) (Table 1). Therefore, this product can be introduced as a rich source of protein. Moreover, due to low lipid content (4.20% d.b) and high crude fiber (62.12%), it can be considered as a good food supplement especially for patients suffering from cardiovascular diseases and used as vegetable salad. Palm heart can be introduced as a cholesterol-free and highly nutritional food and play critical role in facilitating gut movements and prevention from increased blood glucose especially for diabetic patients.

Effect of pH and salt on solubility of PHP

According to the results, linear effect of pH and salt concentration on the solubility of PHP was significant ($p < 0.05$). Moreover, the interaction of salt and pH on protein solubility was also significant. A mean comparison revealed that there was a significant difference among various pHs and salt concentrations (Table 2).

Three regions including acidic, close to an isoelectric point and alkaline points were observed for solubility of PHP. The highest solubility (80.23%) and lowest solubility (13.22%) was observed at pH 9 and pH 3; respectively. Protein solubility occurs when electrostatic repulsion among proteins is stronger than hydrophobic reactions. According to Fig. 1, the lowest solubility occurred at pH 3 which is the isoelectric point of PHP. At this point, proteins have no charge, absorption forces are dominant and molecules tend to aggregate which results in insolubility. By increasing pH from 3 to 9, protein solubility increased significantly. This increased solubility stems from the fact that at pHs higher than isoelectric point, the molecules have a negative charge and solubility increases as a result of electrostatic repulsion among proteins, because at alkaline and acidic pHs, due to increase a negative charge resulting from carboxyl groups and a positive charge resulting from amino groups, electrostatic repulsion among amino acids with the same charge is increased and hence, protein chains are broken up and water can penetrate into protein chains which result in increased solubility (Heywood et al. 2002). Similar results have been reported for kidney bean and field pea protein isolates, where the U

Table 1 Chemical compounds of palm heart and functional properties of PHPI

Chemical compounds	Carbohydrate	Fiber	Ash	Lipid	Protein
Content (%)	58.99 ± 0.35* (14.15**)	12.62 ± 0.24 (3.03)	4.16 ± 0.12 (1.06)	4.20 ± 0.16 (1.06)	20.3 ± 0.62 (4.09)
Functional properties	FS	FC	ES	EC	Purity
Content (%)	60	76	86.33	81	90

*Mean of three replications ± standard deviation

**Percentage of protein, lipid, ash, fiber and carbohydrate based on wet weight was calculated and presented within parenthesis

FS foam stability, FC foaming capacity, ES emulsion stability, EC Emulsifying capacity

Table 2 Analysis of variance (ANOVA) for effect of variables on solubility of PHP

Source of variation	df	Sum of squares	Mean of squares	F value	P value
pH	3	23,555	7851.66	33,885.82	0.0000
Salt concentration	3	969.8	323.27	1395.17	0.0000
Interaction of salt and pH	9	837.2	93.02	401.44	0.0000
Pure error	16	3.7	0.23		
Total	31	25,365.7			

Fig. 1 Effect of pH (a), salt (b) and salt-pH interaction (c) on Solubility of PHP (Piarom cultivar) ($P < 0.01$, $F = 401.44$, $R^2 = 99.99\%$, $R^2_{adj} = 99.97\%$)

shaped protein solubility profile was showed with minimum solubility between pH 4.0 and 5.0 and higher solubility both in acidic and alkaline pHs (Shevkani et al. 2015b). These researcher mentioned that positive relationship between zeta potential and protein solubility indicating that solubility of proteins was closely dependant

upon the charge on the proteins and therefore protein solubility is very effective by pH.

The highest solubility was observed in the concentration of zero (distilled water) and 0.25 M; respectively (Fig. 1). Protein solubility in distilled water was higher than that of other concentrations. The lowest solubility was observed in

1 M concentration. Indeed, protein solubility significantly decreased by an increase in salt concentration ($p < 0.05$). According to the results, there was an inverse relation between protein solubility and salt concentration. According to salting out phenomenon, if salt concentration is gradually increased in a protein solution, it reaches a point where a part of the protein is precipitated. By adding more salt, more protein is precipitated. Protein precipitation occurs when water molecule layers that should be formed around salt ions take water molecules required for hydration of surface charges of protein and thus, protein–protein interaction dominates protein–solvent interaction and hence, the protein begins to precipitate (Kaur and Singh 2007).

By increase in salt concentration within pH of 3–9, protein solubility was decreased (Fig. 1). In all concentrations, protein solubility was reduced by the decrease of pH and the reduction was significant ($p < 0.05$; Table 2). At various pHs except for pH 5, protein solubility was identical at salt concentrations of 0.25 M and 0.5 M; but by an increase in salt concentration up to 0.75, a higher reduction was observed in solubility. Interaction of pH and salt had a positive synergy on reduction of solubility. Indeed, protein solubility at various pHs in presence of salt was higher than that of salt-free media. This phenomenon is due to the fact that in acidic pHs, carboxyl groups have proton and protein has a pure positive charge. The addition of NaCl, Cl ions interact with positively charged proteins which reduce electrostatic repulsion and increases hydrophobic reactions. This situation leads to the higher tendency of proteins to formation of insoluble mass and reduction of solubility. At alkaline pHs, protein has negative charge and a part of this negative charge is neutralized by the positive charge of sodium. As the result, protein solubility at alkaline pHs in presence of salt is lower than that observed in media lacking monovalent and divalent salt (Liu et al. 2010). Based on the results, a salt concentration of 0.25 M and pH 9 can be considered as the best condition for extraction of PHP.

Functional properties of PHPI

Foaming capacity and foam stability

Foaming capacity of PHPI was determined 76% which is higher than that reported for some of the plant proteins. Foaming capacity for flour of red kidney bean, broad bean, mung bean and pea has been reported by Khosravi et al. (2013) to be 68, 64.5, 47 and 35.5%; respectively. Higher foaming capacity of palm heart can be attributed to the high content of proteins especially albumin and low content of polar and nonpolar lipids of this isolate (Kaur and Singh 2005; Lawal et al. 2005). The albumin fraction is

comparatively flexible than globulin fraction which can further reduce the interfacial (surface) tension (Shevkani et al. 2015a); hence, high foaming capacity indicates the presence of high amounts of albumin in the PHPI composition. Also, because globulin is more globular than albumin, so it's less unfold at the air–water interface, which limits capacity of air bubble encapsulation (Ghuman et al. 2016).

As seen in Fig. 2, foam stability reduced through the time. This is due to the fact that bubbles size distribution is changed through the time. By passing the time and as a result of degrading mechanisms, the bubbles attach to each other and enlarged and hence, foam size diminishes (Mirarab et al. 2014). In general, flours, concentrates and protein isolates with suitable foaming capacity is appropriate for being used in some bakery and confectionary products (Bildstein et al. 2008; Martínez et al. 2009). Thus, the palm (Piarom cultivar) heart protein isolate can be used for the production of these foods.

Water holding and fat absorption capacity

Water holding capacity of PHPI was 1.12 ml/g which is almost equal to that reported by Kaur and Singh (2005) for pea flour (1.05–1.17 ml/g) (Kaur and Singh 2005); but is more than those reported for mung bean (0.79 ml/g) and red kidney flour (0.92 ml/g) and pea flour (0.96–0.98 ml/g) (Khosravi et al. 2013). The higher capacity of water holding can be attributed to high the content of cysteine or ability of polar amino acids for the formation of lateral attachments (Heywood et al. 2002). It was concluded that the albumin fraction has a high contribution in PHP; therefore, it can be concluded that high water-holding capacity of the palm heart is due to hydrophilic strength of

Fig. 2 Foam stability of PHPI ($P < 0.01$, $F = 818.09$, $R^2 = 99.62\%$, $R^2_{\text{adj}} = 99.11\%$)

Fig. 3 DSC thermogram of PHPI

its albumins that are able to absorb water molecules. Water holding capacity is a widely used parameter in products such as bread, cake, pasta, soy products, confectionary and gluten free products (Marco and Rosell 2008; Roccia et al. 2009). Moreover, this parameter is an important index in viscous foods such as soups, pastes, meat products and baking products because water retention without protein decomposition is required to provide sufficient viscosity (Sun et al. 2011).

Fat absorption capacity is a physical phenomenon in which, compounds and biopolymers contained in flour or protein isolate cause entrapping and containment of oil drops. This phenomenon is attributed to the interaction of nonpolar protein chains with hydrocarbon side chains of oil and also to protein conformation. Proteins with hydrophobic properties have the higher fat absorption capacity. Variation of these factors results in different values obtained for fat absorption (Kaur and Singh 2007). A high rate of fat absorption by protein is required in foods such as cereals, extenders and meat substitutes, cookies, baking products and soups, Frankfurters, doughnuts and sausages (Zhang et al. 2007). Thus, the palm (Piarom cultivar) heart protein isolate can be used for the production of these food types.

Emulsifying capacity

Emulsifying property of protein biopolymers depends on its ability to lower the surface tension between water and oil within an emulsion. Surface activity causes easy travel of protein, its denaturation and rearrangement in the water and oil interface (Ogungbenle 2008). According to the results, protein isolate of palm heart has a good emulsifying capacity (81%) and hence, can be used in meat products, breads, cakes and soups. High emulsifying capacity is probably due to the availability of numerous hydrophilic and hydrophobic in its protein biopolymers (Khosravi et al. 2013).

Emulsion stability (ES)

Emulsion stability of PHPI was 86.33%. Reduction of ES through the time may be due to increased contact between the droplets and aggregation of oil drops as a dispersed phase. Different ES of a different sample can be attributed to the difference of protein conformations at various ionic strength and also to different protein composition (Lawal et al. 2005).

Thermal analysis of PHPI

Some endothermic phenomena was observed during heating in DSC (Fig. 3). The first endothermic phenomenon is due to the occurrence of physical aging or thermal background of the protein. Then, a glass transition (T_g) was observed and then another endothermic peak occurred which may be due to transformation of regular parts and denaturation of PHP.

Endothermic phenomena were observed in the thermogram of the PHPI (Fig. 3). At first, physical aging occurred which is the main cause of physical changes in food stored at temperatures below glass transition temperature or shows thermal background of proteins (Borde et al. 2002; Denavi et al. 2009). The occurrence of glass transition phenomenon (T_g) in thermal analysis graph of PHPI shows that despite the presence of regular structures in this protein, a part of this structure is amorphous and exhibits that the glass transition as a result of heating (Farahnaky et al. 2005). Shahrabi et al. (2011) observed that glass transition temperature of pea and soybean protein isolates was 88 and 91 °C; respectively which is lower than that obtained for PHPI (93 °C) (Table 3). This is probably due to the fact that there is much more amorphous parts in PHPI.

Denaturation temperature of PHPI was 108.63 °C. Higher thermal stability of PHPI compared to that of many other plant protein isolates is probably due to presence of more hydrogen bonds in PHPI and shows formation of

Table 3 Parameters evaluated by DSC for PHPI

DSC parameters	Tg (°C)			Td (Tp) (°C)	ΔH (J/g)	T ₀ (°C)
	Initial temperature	Midpoint temperature	Final temperature			
Content	100	93	86	108.63	143.1	100

Heating rate was assigned equal to 5 °C min⁻¹; Initial temperature (T₀); Denaturation temperature (Td or Tp); Enthalpy change (ΔH); Glass Transition Temperature (Tg)

more regular crystals in this isolate. Shevkani et al. (2015b) reported denaturation temperature range of 85.7 to 93.3 °C and 82.7 to 85.5 for kidney bean and field pea protein isolates respectively. In many researches, it has been reported that there is a correlation between the denaturation temperature and protein structure and conformations (Tang and Sun 2011; Shevkani et al. 2014, 2015b). The high denaturation temperature is probably due to the high β -sheet conformations (Shevkani et al. 2015b). Therefore, the PHPI structure appears to contain high levels of β -sheet conformations.

Conclusion

As observed, palm heart (cultivar Piarom) has high protein content so that it can be considered as a rich source of protein. Regarding pH effect, the highest solubility was observed in alkaline pH especially pH 9; while the lowest solubility occurred in acidic pH especially about isoelectric point (pH 3). It was observed that protein solubility is inversely related to ionic strength. In general, the salt concentration of 0.25 M and pH 9 can be considered as the best the condition for extraction of PHP. Moreover, it was observed that protein isolate of the palm heart resulting from alkaline extraction and acid precipitation possesses high values of emulsifying properties (emulsifying capacity of 81% and emulsion stability of 86.33%) and foaming properties (foam capacity of 76% and foam stability of 60%). Water and fat absorption capacity of the protein isolate was determined 1.12 ml/g and 1.53 ml/g; respectively. Denaturation and enthalpy changes recorded by DSC was 108.63 °C and 143.1 J/g. as a conclusion, it can be maintained that protein isolate of the palm heart has suitable functional properties and hence can be used as a rich and abundant source of protein and other nutrients in the formulation of various protein-based foods. Results of thermal analysis of the PHPI revealed that it can be used in products treated by thermal processing during preparation since it has high thermal stability. Furthermore, regarding the high cost of animal proteins, using PHP as a substitute for animal proteins can address a part of malnutrition in developing countries. Thus, it is suggested that more

researches be carried out in the field of semi-industrial production of PHPI and its industrial applications.

References

- Bakhshi Moghadam F, Milani E, Mortazavi SA, Meshkani SM (2013) Effect of extraction methods on functional properties of chickpea protein isolated. Iran J Food Sci Tec 10:11–20
- Bildstein M, Lohmann M, Hennigs C, Krause A, Hilz H (2008) An enzyme-based extraction process for the purification and enrichment of vegetable proteins to be applied in bakery products. Eur Food Res Technol 228:177–186
- Borde B, Bizot H, Vigier G, Buleon A (2002) Calorimetric analysis of the structural relaxation in partially hydrated amorphous polysaccharides. I. Glass transition and fragility. Carbohydr Polym 48:83–96
- Boye J, Aksay S, Roufik S, Ribéreau S, Mondor M, Farnworth E, Rajamohamed S (2010) Comparison of the functional properties of pea, chickpea and lentil protein concentrates processed using ultrafiltration and isoelectric precipitation techniques. Food Res Int 43:537–546
- Chandi GK, Sogi D (2007) Functional properties of rice bran protein concentrates. J Food Eng 79:592–597
- Denavi G, Tapia-Blácido DR, Añón MC, Sobral PJA, Mauri AN, Menegalli FC (2009) Effects of drying conditions on some physical properties of soy protein films. J Food Eng 90:341–349
- Farahnaky A, Badii F, Farhat IA, Mitchell JR, Hill SE (2005) Enthalpy relaxation of bovine serum albumin and implications for its storage in the glassy state. Biopolymers 78:69–77
- Garba U, Kaur S (2014) Protein isolates: production, functional properties and application. Int J Cur Res Rev 6:35–45
- Ghumman A, Kaur A, Singh N (2016) Functionality and digestibility of albumins and globulins from lentil and horse gram and their effect on starch rheology. Food Hydrocoll 61:843–850
- Hassan HM, Afify A, Basyiony A, Ahmed GT (2010) Nutritional and functional properties of defatted wheat protein isolates. Aust J Basic Appl Sci 4:348–358
- Heywood A, Myers D, Bailey T, Johnson L (2002) Functional properties of extruded-expelled soybean flours from value-enhanced soybeans. J Am Oil Chem Soc 79:699–702
- Johnson EA, Brekke C (1983) Functional properties of acylated pea protein isolates. J Food Sci 48:722–725
- Kaur M, Singh N (2005) Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. Food Chem 91:403–411
- Kaur M, Singh N (2007) Characterization of protein isolates from different Indian chickpea (*Cicer arietinum* L.) cultivars. Food Chem 102:366–374
- Khosravi Y, Keramat J, Hosaini E, Keshavarz HA, Mahmodi E (2013) Functional properties of Iranian legume flour. J Food Technol Nutr 10:73–80

- Lawal O, Adebawale K, Ogunsanwo B, Sosanwo O, Bankole S (2005) On the functional properties of globulin and albumin protein fractions and flours of African locust bean (*Parkia biglobosa*). *Food Chem* 92:681–691
- Liu C, Wang X, Ma H, Zhang Z, Gao W, Xiao L (2008) Functional properties of protein isolates from soybeans stored under various conditions. *Food Chem* 111:29–37
- Liu S, Elmer C, Low NH, Nickerson MT (2010) Effect of pH on the functional behaviour of pea protein isolate–gum Arabic complexes. *Food Res Int* 43:489–495
- Marco C, Rosell CM (2008) Functional and rheological properties of protein enriched gluten free composite flours. *J Food Eng* 88:94–103
- Martínez KD, Carrera Sánchez C, Rodríguez Patino JM, Pilosof AMR (2009) Interfacial and foaming properties of soy protein and their hydrolysates. *Food Hydrocoll* 23:2149–2157
- Mirarab RS, Mohebbi M, Haddad Khodaparast MH, Koocheki A (2014) Comparisons of some sensory, physical and textural characteristics of chocolate dessert containing different amounts of albumin, sodium caseinat, whey protein concentrate. *J Res Innov Food Sci Tech* 3:375–388
- Movahed A, Mohammadi MM, Akbarzadeh S, Nabipour I, Ramezani N, Hajian N (2011) The heart of date palm: its nutritional and functional constituents. *Iran S Med J* 14:100–105
- Ogunbenle HN (2008) Effects of salt concentrations on the functional properties of some legume flours. *Pak J Nutr* 7:453–458
- Papalamprou EM, Doxastakis GI, Kiosseoglou V (2010) Chickpea protein isolates obtained by wet extraction as emulsifying agents. *J Sci Food Agric* 90:304–313
- Rahbari M, Aalami M, Maghsoudlou Y, Kashaninejad M (2013) Evaluation of solubility properties and electrophoretic patterns of wheat germ proteins. *J Food Process Pres* 2:71–86
- Roccia P, Ribotta PD, Pérez GT, León AE (2009) Influence of soy protein on rheological properties and water retention capacity of wheat gluten. *LWT Food Sci Technol* 42:358–362
- Salvi J, Katewa S (2014) Preliminary assessment of nutritional value of palm heart of *Phoenix sylvestris* (Roxb.). *Int Food Res J* 21:2141–2144
- Shahrabi A, Badii F, Ehsani M, Maftoonazad N, Sarmadizadeh D (2011) Functional and thermal properties of chickpea and soy-protein concentrates and isolates. *Iran J Nutr Sci Food Tec* 6:49–58
- Shevkani K, Singh N, Kaur A, Rana JC (2014) Physicochemical, pasting, and functional properties of Amaranth seed flours: effects of lipids removal. *J Food Sci* 79:1271–1277
- Shevkani K, Kaur A, Kumar S, Singh N (2015a) Cowpea protein isolates: functional properties and application in gluten-free rice muffins. *LWT Food Sci Technol* 63:927–933
- Shevkani K, Singh N, Kaur A, Rana JC (2015b) Structural and functional characterization of kidney bean and field pea protein isolates: a comparative study. *Food Hydrocoll* 43:679–689
- Singh BP, Vij S, Hati S (2014) Functional significance of bioactive peptides derived from soybean. *Peptides* 54:171–179
- Sun J, Li X, Xu X, Zhou G (2011) Influence of various levels of flaxseed gum addition on the water-holding capacities of heat-induced porcine myofibrillar protein. *J Food Sci* 76:C472–C478
- Tang C-H, Sun X (2011) A comparative study of physicochemical and conformational properties in three vicilins from Phaseolus legumes: implications for the structure–function relationship. *Food Hydrocoll* 25:315–324
- Xu L, Diosady L (2002) Removal of phenolic compounds in the production of high-quality canola protein isolates. *Food Res Int* 35:23–30
- Zhang T, Jiang B, Wang Z (2007) Gelation properties of chickpea protein isolates. *Food Hydrocoll* 21:280–286

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.