Turkish Tombul hazelnut (*Corylus avellana* L.) protein concentrates: functional and rheological properties

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Abstract Turkish Tombul hazelnut consumed as natural or processed forms were evaluated to obtain protein concentrate. Defatted hazelnut flour protein (DHFP) and defatted hazelnut cake protein (DHCP) were produced from defatted hazelnut flour (DHF) and defatted hazelnut cake (DHC), respectively. The functional properties (protein solubility, emulsifying properties, foaming capacity, and colour), and dynamic rheological characteristics of protein concentrates were measured. The protein contents of samples varied in the range of 35–48 % (w/w, db) and 91–92 % (w/w, db) for DHF/DHC and DHFP/DHCP samples, respectively. The significant difference for water/fat absorption capacity, emulsion stability between DHF and DHC were determined. On the other hand, the solubility and emulsion activity of DHF and DHC were not significantly different ($p>0.05$). Emulsion stability of DHFP (%46) was higher than that of DHCP (%35) but other functional properties were found similar. According to these results, the DHCP could be used as DHFP in food product formulations. The DHFP and DHCP samples showed different apparent viscosity at the same temperature and concentration, the elastic modulus (G' value) of DHPC was also found higher than that of DHFP samples.

Keywords Hazelnut · Functionality · Protein concentrate · Rheology

Introduction

The Turkish Tombul hazelnut is extensively used as an adjunct in chocolate products and evaluated for making cooking

oil due to its unique and distinctive flavour as an ingredient in a variety of food products and plays a significant role in human nutrition. Turkey is the world's largest hazelnut producer, contributing approximately 70 % to the total global production. In addition, recent report of Black Sea Exporters Association showed that Turkey is responsible of about 80 % of world hazelnut trade totalling approximately 1.8 billion U.S. dollars in 2011 (KIB 2012). The use of hazelnut products as ingredients such as in burgers (Turhan et al. 2005), ice cream (Dervisoglu 2006) and bread (Anil 2007) were reported in literature. Proximate composition of hazelnut is about 62 % fat, 16 % protein and 11 % carbohydrate and changes with variety. Hazelnut composition (Alasalvar et al. 2003; Venkatachalam and Sathe 2006), and good antioxidant effects of hazelnut (Amaral et al. 2006; Oliveira et al. 2008) are reported in literature.

Extraction of nut seed lipids provides the defatted flours that it may also be used as ingredients or in the preparation of protein concentrates/isolates (Sharma et al. 2010). Proteins are important in the food processing and product formulations. Many of plant proteins are used to provide the desirable functional properties, such as fat and water absorption, emulsification, foaming capacity, and colour control to the food materials (Ogunwolu et al. 2009). Therefore proteins are good for salad dressing, sausages, bologna, soups, confectionary, frozen desserts and cakes (Yu et al. 2007). Nut proteins have been studied by a number of investigators, such as peanut protein (Yu et al. 2007), almond protein (Sze-Tao and Sathe 2000), cashew nut protein (Ogunwolu et al. 2009) and Chilean hazelnut protein (Moure et al. 2002). But there are only a few studies (Sharma et al. 2010) about the hazelnut protein concentrates and their functional properties in the literature.

The defatted hazelnut cake is obtained from commercial hazelnut oil processing as by-product and the defatted hazelnut flour is produced with the cold extraction of oil. Both of them could be evaluated in food stuffs due to their high protein content. The commercial hazelnut oil is achieved by hot extraction, which causes a concomitant reduction of

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the product (oil and protein) quality; on the other hand, although the use of cold extraction (lower or avoiding thermal conditioning) reduces the extraction efficiency and thus the protein quality could be better. Since the Turkish Tombul hazelnut products are used as ingredients for many products, its functional properties should be determined. The main objective of this study was to determine the functional and rheological properties of hazelnut flour/cake and protein concentrates and to assess the effect of the extraction type on the characteristics of hazelnut protein.

Materials and methods

Materials

Turkish Tombul hazelnut (*Corylus avellana* L.) was supplied from local market (Giresun, Turkey) and defatted hazelnut cake (DHC) was supplied as gift from the hazelnut oil processing company (Çotanak, Ordu, Turkey).

Preparation of defatted hazelnut flour

The defatted hazelnut flour (DHF) was produced according to the method suggested by Makri et al. (2005) used for the extraction of legume seeds protein. The hazelnuts were ground in a laboratory blender (Waring Commercial, CT, USA) and the resulting flour was treated with n-hexane (1/3 (w/w)) to remove the fat with constant magnetic stirring for 2 h for three times at ambient temperature. The suspension was centrifuged at 3,000 g for 15 min and the supernatant was decanted. Obtained the defatted meals were spread a stainless tray and were dried under the vacuum at 60 °C for 3 h.

Preparation of protein concentrates

For the production of protein concentrates, defatted hazelnut flour (DHF) and defatted hazelnut cake (DHC) were mixed with water at ambient temperature at flour to water ratios of 1/12 (w/w). The suspension was adjusted to maximum solubility at pH 9.5 (determined preliminary test) with 1 N NaOH and stirred using a magnetic stirrer for 1 h, followed by centrifuging at 3,000 g for 15 min. The slurry was removed and the supernatant was adjusted to pH 4.5 with 1 N HCl and then it was centrifuged at 3,000 g for 15 min. The supernatant was discarded and precipitate was dried under the vacuum overnight at 60 °C and ground into powder. The dry protein concentrate powder was stored in refrigerator (4 °C) until use in functionality tests.

In this study, we chose the pH range of 4.0–4.5 which was in agreement with the isoelectric point of different nuts (Yu et al. 2007; Zhang et al. 2007; Wu et al. 2009; Ogunwolu et al. 2009).

Analyzes

Proximate composition

Moisture Accurately weighted samples (~3 g) were placed in an aluminium pan and dried in the previously heated (105°C) oven (Binder ED 53) for gravimetric analysis.

Ash Accurately weighted samples (~3 g) were placed in ceramic crucible and subjected ashing in the ash furnace maintained at 550°C until a constant final weight for ash was achieved.

Fat Fat was determined using the Soxhlet method. Accurately weighted samples (~3 g) were placed cartridge. Samples were washed up with diethyl ether until all fat which in sample had been taken.

Protein Total protein was determined using the Kjeldahl method and the conversion factor of 6.25 was used for samples.

Soluble protein Soluble protein content of samples was determined using the method described by Lowry et al. (1951) using bovine serum albumin (purity 98 %, Sigma Chemical Co., St. Louis, MO). To assess protein solubilisation, prepared hazelnut flour solutions and solutions pH were assayed 3.0, 7.0 and 9.5 with 0.1 N NaOH and 0.1 N HCl. Then solutions were centrifuged and supernatant was analyzed.

Functional properties

Colour Colour values of samples was evaluated using Minolta Colorimeter which provided the L, a and b values correspond to whiteness, greenness, or redness and yellowness or blueness, respectively. All samples were weighted 15 g in glass sample cup and the average values of five measurements were reported.

Water absorption capacity (WAC) Water absorption capacity was determined using the method described by Yu et al. (2007); one gram hazelnut flour and protein concentrate were mixed with 10 ml of distilled water using a vortex at the highest speed for 2 min. After the mixture samples were incubated at room temperature for 30 min, and then centrifuged at 3,000 g for 20 min at 20°C. The supernatant was decanted, and the tubes were drained for 10 min. The centrifuge tube containing sediment was weighed (Eq. (1));

$$WAC = (W_2 - W_1) / W_0 \quad (1)$$

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).

Fat absorption capacity (FAC) Fat absorption capacity was determined using the method described by Yu et al. (2007). One gram (W_0) of protein weight centrifuge tubes and mixed with 10 mL (V_1) of sunflower oil (Orkide, İstanbul) using vortex-mixed for 2 min. The emulsion was incubated at room temperature for 30 min, and then centrifuged at 3,000 g for 20 min at 20°C. The supernatant was decanted into 10 mL graduated cylinder, and the volume was recorded (V_2). Fat absorption capacity was calculated (Eq. (2));

$$FAC = (V_1 - V_2) / W_0 \quad (2)$$

Foaming capacity and stability Foaming capacity and stability of samples were determined according to Sathe and Salunkhe (1981). 50 ml of %1 (w/v) protein concentrate solution of appropriate pH was whipped for 3 min in a homogenizer (WiseTis Homogenizer HG-15D, Germany) and then poured into a 100 mL graduated cylinder. pH of protein solution was adjusted the desired pH value with 0.1 N HCl and 0.1 N NaOH. We chose pH 5.0 because it is closer to the isoelectric pH of hazelnut and choice of pH 9.5 was based on effectively solubilising of proteins at this pH. The total sample volume was taken at 0 min for foaming capacity (Eq. (3)) and 60 min for foaming stability (Eq. (4));

$$\text{Foaming capacity (FC)(\%)} : \frac{(\text{Volume after whipping} - \text{volume before whipping}) \text{ml}}{(\text{Volume before whipping}) \text{ml}} (t = 0 \text{min}) \quad (3)$$

$$\text{Foaming stability (FS)(\%)} : \frac{(\text{Volume after standing} - \text{volume before whipping}) \text{ml}}{(\text{Volume before whipping}) \text{ml}} (t = 60 \text{min}) \quad (4)$$

Emulsifying activity and stability Emulsion activity and emulsion stability were determined with the method reported by Moure et al. (2002). Briefly, twenty millilitres of 0.1 % (w/v) protein solutions were homogenized with 6.6 mL of sunflower oil (Orkide, İstanbul) during 1 min in a homogenizer. After homogenization, aliquots of 50 µl of the emulsion were diluted to 5 ml with a 0.1 % sodium dodecyl sulfate (SDS) solution and their absorbance were determined at 500 nm in a spectrophotometer. Emulsion activity index (EAI) was calculated according to Pearce and Kinsella (1978). Emulsion stability index (ESI) was measured at 0 and 60 min (Eq. (5));

$$ESI = (T_0 \times t) / (T_0 - T_{10}) \quad (5)$$

T_0 Turbidity at 0 min
 T_{10} Turbidity at 10 min after the homogenization
 t 10 min.

Rheological properties of protein concentrate

To evaluate the DHFP and DHCP as a possible use of ingredient, rheological properties of samples were determined. Dynamic measurements were conducted using a rheometer Haake Mars III (Thermo Scientific, Germany). The measuring system consisted of cone-plate geometry (diameter 35 mm, gap 0.104 mm and cone angle 2°). Different stock protein solutions (1 %, 5 %, and 10 % (w/w)) were prepared with

protein concentrates in distilled water. Tests performed at 5°C and 20°C. Apparent viscosity was measured in the range of shear rate 0–100 s⁻¹ continued 300 s. The relationship between viscosity and shear rates were described by Herschel-Bulkley model (Eq. (6));

$$\eta = \tau_0 / \dot{\gamma} + K \dot{\gamma}^{(n-1)} \quad (6)$$

where η is the viscosity (Pa.s), τ_0 is the yield stress (Pa), $\dot{\gamma}$ is the shear rate in (1/s), K is the consistency index and n is the flow behaviour index.

Temperature sweep tests were conducted in the range of 10–90°C to evaluate the temperature dependency of rheological behaviours. Frequency sweeps from 0.1 to 10 Hz were applied to samples at 20°C. The elastic modulus (G') and viscous modulus (G'') were measured. The elastic modulus and the viscous modulus can be used as a measure of the elastic component of the sample and the viscous component of the sample, respectively. The frequency sweep curve gives a good rheological description of how the product will behave during storage and application.

Statistics analysis

Data were analyzed for statistical significance ($p=0.05$) using one-way ANOVA by SPSS statistical software (SPSS 16.0 for Windows) and Tukey's test were used to establish the significance of differences among the mean values.

Results and discussion

Proximate composition

Moisture, ash, fat, protein

The defatted hazelnut flour (DHF) contained about 22 % fat, 6 % ash and 35 % protein (w/w, db). Defatted hazelnut cake (DHC) contained 2 % fat, 7 % ash and 45 % protein (w/w, db). The chemical composition of hazelnut protein samples were influenced by the type of hazelnut flour and cake. The reason of the higher fat content of DHF than the DHC is the using cold extraction for production of DHF. The defatted hazelnut flour protein (DHFP) and defatted hazelnut cake protein (DHCP) samples had higher protein (84.43 % and 74.98 %) and lower fat content (5.90 % and 0.61 %) than DHF and DHC samples. The ash contents in the DHFP and DHCP were much lower than in the DHF and DHC samples. Proteins were calculated on a dry base for the DHFP and DHCP as 91 % and 92 %, respectively.

Soluble protein

Protein solubility is very important functional property because it influences other functional properties such as foaming and emulsifying stability. Figure 1 shows that the pH had a significant effect on the soluble protein of defatted hazelnut flour (DHF) and defatted hazelnut cake (DHC). The maximum protein solubility of samples occurred at pH 9.5 (Fig. 1). The protein solubility of DHF at acidic and alkaline pH was more than that of DHC but there was no significant difference ($p>0.05$). Also at neutral pH, the solubility of DHF and DHC were similar. Sharma et al. (2010) reported the hazelnut protein solubility around 8–10 mg protein/ml. In our study, protein solubility of DHF and DHC found as 15 and 11 mg protein/100 mg flour/cake, respectively. Our results on the influence of pH on hazelnut protein solubility may be comparable favourably with the influence of pH on almond (Sathe 1992), cashew nut (Sathe 1994), walnut (Sze-Tao and Sathe 2000) protein solubility.

Functional properties

Colour

The defatted hazelnut flour, cake and their proteins were typically dark beige to brown colour. The L values of samples were significantly different from each other ($p<0.05$), the L value of the DHC and DHCP (48.99 and 33.12) were lower than that of DHF and DHFP (68.17 and 49.60). The colour a and b values, respectively are indicative of redness and yellowness. These values depend on the combination of several components including quantity of total phenolics,

Fig. 1 Effects of pH on defatted hazelnut flour (DHF) and defatted hazelnut cake (DHC) concentrate at flour/water ratio 1/12 (w/w). Percentage of soluble protein was calculated at dry flour basis. Data are mean $\pm$ standard deviation ($n=2$)

colouring pigments and minerals and type of phenolic compounds (Sharma et al. 2010). The a values (redness) of DHC and DHCP (5.34 and 5.28) were not significantly different ($p>0.05$). But the redness value of DHFP (5.74) was more than DHF (3.71). The b values of samples were statistically different ($p<0.05$). The yellowness of the DHF and DHFP (18.61 and 16.18) were higher than that of DHC and DHCP (11.27 and 7.3).

Water absorption capacity (WAC) and fat absorption capacity (FAC)

In the food processing, proteins are affected from the water and fat interactions. Fat absorption capacity of proteins is known to be dependent on protein surface properties (electrical charge, area and hydrophobicity) (Kimura et al. 2008). High fat absorption by the protein concentrates indicates their good emulsifying agent for food industry. So these proteins may be used as ingredients in developing high protein value-added products. Although water absorption capacity (WAC) of DHF, DHFP, DHCP were not significantly different ($p>0.05$) from each other (Table 1), the DHC exhibited the highest water absorption capacity (4.10 g water/g flour). It is possible that hazelnut cake indicated impurity like dietary fibres. Similarly, fat absorption capacity (FAC) of DHFP and DHCP were not significantly different ($p>0.05$). The DHCP had the lowest fat absorption capacity (1.86 mL fat/g protein). Besides WAC and FAC of defatted hazelnut flour and cake were higher than their protein concentrates. WAC and FAC values of DHFP and DHF were higher than peanut flour (1.0 and 1.67 ml/g) and peanut protein concentrate (0.83 and 1.0 ml/g) processed by the same method as reported by Yu et al. (2007). WAC of peanut

Table 1 Some functional properties of defatted hazelnut flour (DHF) and defatted hazelnut cake (DHC), defatted hazelnut flour protein (DHFP) and defatted hazelnut cake protein (DHCP) at their natural pH

Functional Properties	DHF	DHC	DHFP	DHCP
Water absorption capacity (g/g)	1.49±0.03 ^a	4.10±0.73 ^b	1.16±0.05 ^a	1.36±0.12 ^a
Fat absorption capacity (ml/g)	4.02±0.11 ^b	3.38±0.11 ^c	2.07±0.27 ^a	1.86±0.17 ^a
Emulsion activity index (%)	29.12±6.57 ^a	22.59±3.61 ^a	20.76±3.62 ^a	20.45±1.29 ^a
Emulsion stability index (%)	50.35±4.90 ^a	31.90±2.43 ^b	45.67±3.75 ^a	34.73±4.41 ^b

Data are mean±standard deviation ($n=3$)

Means within columns with different letter (a,b or c) are significantly different ($p<0.05$)

flour and peanut protein concentrate had 1.0 and 0.83 ml/g, respectively. Similarly, Sharma et al. (2010) reported that the oil absorption capacity of protein preparations absorbed more than twice own weight, ranging from 2.8 (macadamia) to 7 (soybean) g of oil/g of protein and hazelnut protein exhibited fat absorption capacity of ~3 g/g of protein.

Foaming capacity and stability

Foam can be defined as a two-phase system consisting of air cells separated by thin continuous liquid layer called the lamellar phase (Makri et al. 2005). Total foam volume varied from 54 to 51 mL for defatted hazelnut flour protein (DHFP) and defatted hazelnut cake protein (DHCP). The foaming capacities of both DHFP and DHCP were found 8 % and 2 % at pH 9.5 and pH 5.0, respectively (Fig. 2). At pH 9.5, the foam stability of DHFP (7 %) was slightly higher than that of the DHCP (6 %) but there was no significant difference ($p>0.05$) between them. On the other hand, at the acid pH (pH 5.0), the foam stability of DHFP and DHCP was found

similar as 2 %. Sharma et al. (2010) reported that hazelnuts protein had the least foaming capacity and stability among the tested nut samples probably due to their compact globular structures as they are unable to form strong elastic films around air bubbles, they do not appear to be good foaming agents. In our study, defatted hazelnut cake and flour showed zero foaming capacity. Therefore, defatted hazelnut cake may not be suitable in food system that requires foaming such cake and bread. Similarly, Neto et al. (2001) reported poor foaming properties of cashew nut protein isolate, almond flour and protein concentrate, respectively. In addition, observed zero foam capacity for DHC in this study is similar to those of heat-treated soy bean and cow pea flours (Obatolu and Cole 2000)

Emulsifying activity and stability

Proteins generally have good emulsifying properties and they are often used in food emulsions. 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 (Yu et al. 2007). Emulsifying activity index (EAI) of samples at natural pH (6.5–7.5) was not significantly different ($p>0.05$) but and emulsifying stability index (ESI) was significantly different ($p<0.05$). Emulsion stability of defatted hazelnut flour (DHF) and protein (DHFP) was higher than that of defatted hazelnut cake (DHC) and protein (DHCP) (Table 1). Since heating could significantly reduce the emulsion stability of sunflower meals (Venkatesh and Prakash 1993), drying led to cake samples having a lower EAI and ESI lower than their flour counterparts. Also Moure et al. (2002) reported that emulsions formed with meals of Chilean hazelnut, from cold-pressed seeds were more stable than those from thermally conditioned. The EAI and ESI were found as similar to those of Chilean hazelnut (Moure et al. 2002), almond (Sze-Tao and Sathe 2000), cashew (Ogunwolu et al. 2009) protein concentrates.

Fig. 2 Foaming capacity and stability of defatted hazelnut flour protein (DHFP) and defatted hazelnut cake protein (DHCP). Data are mean±standard deviation ($n=3$)

Fig. 3 Representative flow curve shear rate vs. shear stress at different concentrations of Defatted hazelnut flour protein (DHFP) and Defatted hazelnut cake protein (DHCP) at 20°C and 5°C. DHFP dispersions were measured 1 % w/w (triangle), 5 % w/w (white square) and 10 % w/w

(white circle) total solids at 5°C (a) and 20°C (b). DHCP dispersions were measured 1 % w/w (triangle), 5 % w/w (white square) and 10 % w/w (white circle) total solids at 5°C (c) and 20°C (d)

Fig. 4 Temperature sweep (10–90°C) of defatted hazelnut flour protein (DHFP) dispersion was measured 1 % w/w (triangle), 5 % w/w (white square) and 10 % w/w (white circle) total solids.

Rheological properties of protein concentrate

Characterization of the flow curve

The shear stress was higher at low shear rates while it gradually decreased as the shear rate increased and showed nearly Newtonian behaviour. Figure 3 shows a representative flow curve shear rate vs. shear stress at different concentrations of hazelnut samples. The DHFP and DHCP showed different rheological characteristics at the same temperature and concentration, this was probably due the fibres and insoluble particles. Although the samples showed nearly Newtonian character at higher shear rates to determine the exact relationship between viscosities and shear rates, Herschel-Bulkley (H-B) model (Eq. 6) is used. H-B model is adequate for the modelling of viscosity curve. Computed values of the constants (K , τ_0 and n) of H-B model at 5 °C and 20 °C are

Table 2 The coefficients of Herschel-Bulkley model^a for forward steady flow curve (shear rate: 1–100 s⁻¹ and time: 300 s) and viscosity of different temperatures and different concentrations of defatted hazelnut flour protein concentrate and defatted hazelnut cake protein concentration solutions

5 °C						20 °C				
	C ^b	R ² ^c	τ ₀	K	n	C	R ²	τ ₀	K	n
DHFP ^d	% 1	0.999	0.14	1140	1.33×10 ⁻⁵	% 1	0.999	0.65	3.16	2.88×10 ⁻²
	% 5	0.912	0.15	1147	1.87×10 ⁻³	% 5	0.942	0.12	21.40	1.40×10 ⁻¹
	% 10	0.938	0.79	1148	2.21×10 ⁻³	% 10	0.951	1.57	54.52	1.58×10 ⁻¹
DHCP ^e	% 1	0.851	0.48	1187	9.71×10 ⁻³	% 1	0.823	0.09	430	4.02×10 ⁻²
	% 5	0.942	2.81	1229	1.29×10 ⁻²	% 5	0.989	0.36	2076	3.12×10 ⁻²
	% 10	0.996	2.41	1260	1.49×10 ⁻²	% 10	0.969	2.30	1997	1.41×10 ⁻²

^a $\eta = \tau_0 / \dot{\gamma} + K \dot{\gamma}^{(n-1)}$ η : viscosity (Pa.s), τ_0 : yield stress (Pa), $\dot{\gamma}$: shear rate (s⁻¹), K: Consistency index, n: flow behavior index

^b C: concentration ^c R²: correlation coefficients

^d DHFP: Defatted Hazelnut Flour Protein ^e DHCP: Defatted Hazelnut Cake Protein

reported Table 2. The correlation coefficients (R^2) values ranged from 0.851 to 0.999 and 0.823 to 0.999 of 5°C and 20°C, respectively. The yield stress (τ_0) and the consistency index (K) increased with increasing concentration of samples. Similarly, increased in K as the concentration increased, has been reported by Hagenimana et al. (2007). Yield stress (τ_0), represents the minimum stress that is needed to initiate flow (Hagenimana et al. 2007). There were no appreciable different values of the yield stress, they ranged from at 5°C, 0.14 to 0.79 and 0.48 to 2.41 and from at 20°C, 0.65 to 1.57 and 0.09 to 2.30, samples of DHFP and DHCP, respectively. Flow behaviour index (n) indicates the behaviour of the fluid. It varied from 1.33×10^{-5} to 1.49×10^{-2} and 2.88×10^{-2} to 1.58×10^{-2} at 5 °C and 20°C, respectively. Apparent viscosity of the protein

solutions increased with increased protein concentration. Sharma et al. (2010) reported that the difference in viscosity was significant at protein concentrations of 7 and 10 % and the apparent viscosity of DHCP increased with increased temperature at 10 % concentration.

Temperature sweep test

The temperature sweep test of DHFP showed that viscosity decreased with increased temperature but apparent viscosity increased with increased concentration (1, 5, 10 %) (Fig. 4). However, upon heating to 80°C, probably because of the denaturation, the viscosity of DHFP suspension increased sharply.

Fig. 5 Frequency sweeps (0.1–10 Hz) at a constant temperature of 20 °C. (G') and (G'') are the elastic modulus and viscous modulus, respectively. **a** Defatted hazelnut flour protein (DHFP) dispersions were measured 1 % w/w (triangle), 5 % w/w (white square) and 10 % w/w

(white circle) total solids. **b** Defatted hazelnut cake protein (DHCP) dispersions were measured 1 % w/w (triangle), 5 % w/w (white square) and 10 % w/w (white circle) total solids

Frequency sweep

Dynamic oscillatory frequency sweeps were used to characterize rheological behaviour of dispersions at 20°C (Fig. 5a–b). (G') and (G'') are the elastic modulus and viscous modulus, respectively. (G') was greater than (G'') by roughly on order of magnitude across the frequency range. (G') and (G'') were increased with increasing concentration. In addition, DHCP was showed greater elastic behaviour than DHFP samples.

Conclusions

Defatted hazelnut cake (DHC) and defatted hazelnut cake protein (DHCP) showed low emulsifying stability, fat absorption capacity than defatted hazelnut flour (DHF) and defatted hazelnut flour protein (DHFP). Purification process improves the functionality of DHFP and DHCP. The pH affects the hazelnut solubility and higher solubility was seen at the alkaline pH than at the acidic pH. Since hazelnut protein concentrate has suitable water and oil absorption capacity, emulsifying properties, they can be used in breads, cakes, meats, sausages, soups. Because of defatted hazelnut flour and cake are suitable functional properties, they could be developed as an ingredient to supply protein in the food industry. The production of protein concentrates could be also adds value to defatted flour, a low value by-product of hazelnut oil production.

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