



# Application of TOPSIS methodology to determine optimum hazelnut cake concentration and high pressure homogenization condition for hazelnut milk production based on physicochemical, structural and sensory properties

Osman Gul<sup>1</sup> · Ilyas Atalar<sup>2</sup> · Mustafa Mortas<sup>2</sup> · Furkan Turker Saricaoglu<sup>3</sup> · Fehmi Yazıcı<sup>2</sup>

Received: 16 October 2017 / Accepted: 14 June 2018 / Published online: 19 June 2018  
© Springer Science+Business Media, LLC, part of Springer Nature 2018

## Abstract

Vegetable milks containing antioxidants, fatty acids and vitamins can be recommended as an alternative to animal milks cause some health problems like lactose intolerance and milk protein allergy. Hazelnut oil cake which is a waste from hazelnut oil production cannot be used for human nutrition. Cold press hazelnut cake must be evaluation as food materials. The aim of this study was to evaluate the effect of cold pressed hazelnut cake concentration (5, 10, 15% w/v) and high pressure homogenization (HPH) (up to 100 MPa) on the physicochemical, structural and sensory properties of hazelnut milk and also determined the best conditions for hazelnut milk production by TOPSIS approach. Hazelnut milks produced from 15% hazelnut cake had the best physicochemical properties and physical stability, but the sensory properties of the milks were not acceptable due to viscoelastic behaviors. Physicochemical properties, physical stability and sensory characteristics of hazelnut milks were significantly affected by homogenization pressure ( $P < 0.05$ ). Colloidal stability and sensory properties of hazelnut milks were improved by increasing homogenization pressure. The viscosity values of hazelnut milks with 10 and 15% hazelnut cakes were significantly decreased by increasing the homogenization pressure. TOPSIS approach showed that 10% hazelnut cake concentration and 100 MPa homogenization pressure was the best condition for an acceptable hazelnut milk production.

**Keywords** Byproducts · Hazelnut milk · High pressure homogenization · Microstructure · Multi-criteria decision technique

## Introduction

Milk is one of the most nutritious foods in terms of complex and balanced essential nutrients required for growth and development of human health [1]. It has a positive effect on healthy life as regulating body function and/or prevention of some disease. Recently, the demand for vegetable based

products has been increasing because of lactose intolerance, allergy to animal milk and changing food preferences [2, 3]. Vegetable or plant milks mainly made from nuts and cereals can be recommended as alternative products. Soy milk is the best known vegetable milk and the others are almond, coconut and rice milks. Vegetable milks are rich in unsaturated fatty acids, vitamins, fibers, and antioxidants [1] and do not contain any lactose and cholesterol. Soy and almond beverages have higher nutritional value and functionality [4] and nuts used for vegetable milk production are the most important source of nutritious food with high energy content [5]. Wide range of vegetable milks such as sweetened, unsweetened, low-fat, fortified and flavored increases the demand and the market share compared to dairy milk products, the market size for soy, rice, almond and other plant milks reached to almost 1.5 billion dollars in 2011 in USA and the same situation is valid for Europe as European

✉ Osman Gul  
osman.gul@omu.edu.tr

<sup>1</sup> Program of Food Technology, Yeşilyurt Demir–Celik Vocational School, Ondokuz Mayıs University, 55300 Samsun, Turkey

<sup>2</sup> Food Engineering Department, Engineering Faculty, Ondokuz Mayıs University, Samsun, Turkey

<sup>3</sup> Food Engineering Department, Faculty of Natural Sciences, Architecture and Engineering Bursa Technical University, Bursa, Turkey

nondairy milk sales including soybean are increasing by over 20% every year [6].

Although hazelnut milk is one of the most promising vegetable milk products, it is not commonly consumed in comparison to soy or almond milk because of its availability and price. Hazelnut is one of the most expensive nuts commonly used for chocolate products and hazelnut oil production. Hazardous extraction solvent has been used in hazelnut oil production and the hazelnut cakes from oil production are utilized for animal feeding. On the other hand, cold press oil production yields hazelnut cake that is safer and nutritious because of minimal treatment procedure. So, cold press hazelnut cake is a valuable ingredient for producing hazelnut beverage. Hazelnut beverage, due to its nutritional and nutraceutical properties, may become an alternative to animal milks [7]. According to Bernat et al. [2] hazelnut beverage has been used as an alternative to milk for lactose-intolerant people, pregnant and celiac people because of its high calcium, phosphorous and potassium levels. In addition, hazelnut plays a major role in human nutrition and health due to its low sodium and high monounsaturated fatty acids, protein, carbohydrate, dietary fiber, vitamins (vitamin E), phytosterols, squalene, and antioxidant phenols [8, 9].

High pressure homogenization is well known treatment for its improving effect on the physical properties of milk beverages such as deflocculation of clusters of primary fat globules and uniform dispersion of agglomerates [10], changes in protein conformation, increase of emulsion stability [11], inactivation of enzyme and microorganism [12, 13] and reduction in particle size [14]. It also enhances organoleptic, textural and nutritional properties of food ingredients [15]. Although, many researches have been conducted to improve the physicochemical properties of vegetable milks such as almond, hazelnut, walnut and soy milk by high pressure homogenization process [2, 16, 17], there is limited study related to hazelnut milk production from cold press hazelnut cake. Therefore, the aim of this study is to evaluate the effect of cold press hazelnut cake concentration and high pressure homogenization on the physicochemical properties, physical stability and sensory characteristics of hazelnut milk and to determine the optimum hazelnut cake concentration and homogenization pressure by the technique for order preference by similarity to ideal solution (TOPSIS) approach.

## Materials and Methods

### Materials

Whitened hazelnuts were obtained from Gursoy Hazelnut Production Factory (Ordu, Turkey). Hazelnuts (*Corylus colurna*) harvested at the Black Sea Region of Turkey were

applied for removing shells-brown skin and roasting as a pretreatment. The oil was removed from hazelnut by using a headed cold press machine (Ekotok 1, Izmir, Turkey). The cold press hazelnut cake (4.78% moisture, 95.22% dry matter, 48.23% protein, 31.42% carbohydrate, 9.78% lipid, and 5.79% ash) was used as a main ingredient for the milk production. The AOAC methods [18] were used for proximate analyses of hazelnut milks as moisture content (method 934.06), protein content (method 920.152), total fat content (method 920.39C) and ash content (method 940.26). The percentage of total carbohydrates was determined by difference the total percentage of other components from 100.

### Preparation of hazelnut milks

After removing oil from hazelnut by a headed cold press machine, the samples were grounded by using blender (Waring laboratory blender, Conair Corporation, Stamford, CT, USA) for 10 min. The grounded hazelnuts were mixed with distilled water with different nut-water ratios (5, 10, and 15%, w/v). The hazelnut-water mixture was homogenized with the homogenizer at 10,000 rpm for 10 min (IKA-Werke GmbH & Co. KG, Staufen, Germany). High pressure homogenization treatments at 40, 60, 80 and 100 MPa were applied to each milk by using two stage homogenizator (GEA Niro—Panda PLUS 2000 Homogenizer, GEA Niro Soavi S.P.A., Parma, Italy).

### Total solids, pH and °Brix of hazelnut milks

Total solids were determined gravimetrically by using an oven at 105 °C until a constant weight was obtained [18]. pH values of the samples were measured with a calibrated pH meter at 25 °C (Eutech Cyberscan pH 2700, Ayer Rajah Crescent, Singapore). Total soluble solids of hazelnut milk samples as °Brix were determined at 20 °C using with refractometer.

### Particle size distribution

Particle size distribution (span), average particle size ( $d_{50}$ ), volume mean diameter ( $D_{4,3}$ ) and surface mean diameter ( $D_{3,2}$ ) of hazelnut milks were measured with a laser diffractometer Mastersizer 2000 (Malvern Instruments Ltd, Worcestershire, UK). Particle size distributions of hazelnut milks were expressed as the span which is defined as:

$$\text{Span} = d_{90} - d_{10} / d_{50} \quad (1)$$

where  $d_{90}$ ,  $d_{10}$  and  $d_{50}$  are the equivalent volume diameters at 90, 10 and 50 cumulative volume, respectively.

## Rheological measurements

Rheological analyses of hazelnut milks were conducted by using Haake Mars III rheometer (Thermo Scientific, Germany) with a cone and plate system (35 mm diameter, 0.105 mm gap,  $c2^\circ$  angle). Temperature control was carried out with circulator water bath at 25 °C. Flow behavior of samples was measured by recording shear stress values when shearing the samples at linearly increasing shear rates from 1 to 100  $s^{-1}$  through 120 s. The relationship between shear stress and shear rate was described by Ostwald-de-Waele model (Eq. 2).

$$\eta_{app} = K\dot{\gamma}^{n-1} \quad (2)$$

where  $\eta_{app}$  is apparent viscosity (Pa.s),  $\dot{\gamma}$  the shear rate ( $s^{-1}$ ),  $K$  the consistency index ( $Pa.s^n$ ) and  $n$  the flow behavior index (dimensionless). Rheowin 4 Data Manager software (version 4.20, Haake) was used for calculations.

## Colloidal stability

Colloidal stability of the hazelnut milk samples was determined via separation of phase during their storage time at 4 °C. For this purpose, the hazelnut milk samples were transferred into 50 mL measured tubes and the heights of the separated phases were quantified at 0, 1st, 3rd, 5th and 7th days. Colloidal stability was expressed as sedimentation index and calculated as follows [19]:

$$\text{Sedimentation index (\%)} = \frac{V_n}{V_0} * 100 \quad (3)$$

where  $V_n$  is the sedimentation volume at storage time (mL) and  $V_0$  is the initial volume (mL).

## Protein solubility

Protein solubility of homogenized and untreated hazelnut milk samples were determined by using the Biuret method [20]. The sample (1 mL) was mixed with 1 mL of Biuret reagent and homogenized by vortex for 1 min. After 20 min, waiting, the absorbance of sample was measured at 550 nm by UV spectrometer (Helios Gamma, Cambridge, UK) and protein solubility was calculated from a standard curve of Bovine Serum Albumin (BSA).

## Color properties

Color values ( $L^*$ ,  $a^*$  and  $b^*$ ) of the samples were measured by using a colorimeter (Minolta Chroma Meter, CR-400, Osaka, Japan). Color values as  $L^*$  (Lightness),  $a^*$

(red-green) and  $b^*$  (yellow-blue) were used for evaluating for Chroma ( $C^*_{ab}$ ) (Eq. 4), hue ( $h^*_{ab}$ ) (Eq. 5), whiteness index (WI) (Eq. 6) and color difference ( $\Delta E$ ) (Eq. 7).

$$\text{Chroma} = C^*_{ab} = (a^{*2} + b^{*2})^{0.5} \quad (4)$$

$$\text{Hue} = h^*_{ab} = \tan^{-1} \left( \frac{b^*}{a^*} \right) \quad (5)$$

$$\text{Whiteness index} = \text{WI} = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (6)$$

$$\text{Colour difference} = \Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

## Sensory analysis

The twelve trained panelists chosen from staffs of the Ondokuz Mayıs University, Food Engineering Department performed sensory analysis of the samples. The panelists evaluated the sensory properties of samples according to color-appearance, texture-consistency, taste–aroma, consuming performance, smell-aroma and general acceptability. In addition, the samples were coded randomly as different three-digit number and served randomly to the panelists. It was rated according to scores on an ordered but arbitrary scale, such as a 5-point hedonic scale (1 = very bad, 2 = bad, 3 = fair, 4 = good and 5 = very good) by panelists.

## Application of TOPSIS approach

Technique for order preference by similarity to ideal solution (TOPSIS) approach is one of the useful multi-criteria decision-making techniques that provides a decision hierarchy and requires pairwise comparison between criteria [21, 22]. TOPSIS approach determines solution alternatives from the positive ideal solution and negative ideals solution and the best alternative is the nearest to the positive ideal solution and farthest from the negative ideal solution [22, 23]. In this study, TOPSIS approach was performed for determined the optimum hazelnut cake concentration and homogenization pressure in the hazelnut milk production. Hazelnut cake concentration (5, 10 and 15% w/v) and homogenization pressure (40, 60, 80 and 100 MPa) was selected decision marker and selection criteria were chosen as °Brix, average particle size, viscosity, colloidal stability, protein solubility, color difference and general acceptability. The average particle size, viscosity and color difference was considered negative criteria; others are considered positive criteria. The determining the final ranking of hazelnut milks, TOPSIS approach is calculated as follows [21]:

In the first step, a decision matrix ( $A_{ij}$ ) was established

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{8}$$

where  $m$  and  $n$  are decision points and evaluation indicators, respectively.

In the second step, the decision matrix was normalized by using Eq. 9,

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^m a_{kj}^2}} \quad k = 1, 2, 3, \dots, i, \dots, k, \quad i = 1, 2, \dots \tag{9}$$

where  $x_{ij}$  is normalized value and  $a_{ij}$  is real value of the criteria.

Obtained normalized matrix ( $N$ ) as following,

$$N_{ij} = \begin{bmatrix} n_{11} & n_{12} & \dots & n_{1n} \\ n_{21} & n_{22} & \dots & n_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ n_{m1} & n_{m2} & \dots & n_{mn} \end{bmatrix} \tag{10}$$

In the third step, calculate the weighted normalized decision ( $V$ ) matrix was calculated using Eq. 11.

$$v_{ij} = x_{ij} \times w_{ij} \tag{11}$$

where  $V_{ij}$  is the weighed normalized value, and  $W_{ij}$  is the weight of each criterion. The weight of °Briks, average particle size, viscosity, colloidal stability, protein solubility, color difference and general acceptability in the decision matrix were determined as 0.1, 0.15, 0.15, 0.15, 0.15, 0.1 and 0.2 by the staff of the Food Engineering Department in Ondokuz Mayıs University.

In the fourth step, positive ( $A^*$ ) and negative ( $A^-$ ) ideal solutions are determined using Eqs. 12 and 13, respectively.

$$A^* = \left\{ (\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J') \right\} \text{ or } A^* = \{v_1^*, v_2^*, \dots, v_n^*\} \tag{12}$$

$$A^- = \left\{ (\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J') \right\} \text{ or } A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \tag{13}$$

where  $J$  is benefit criteria (maximization) and  $J'$  is cost criteria (minimization) for both formulas.

In the fifth step, the distance of each alternative from the positive and negative ideal solution was determined using Eqs. 14 and 15, respectively.

$$d_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \tag{14}$$

$$d_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \tag{15}$$

where  $d_i^*$  and  $d_i^-$ , are distance of alternative from positive and negative ideal solutions, respectively.

In the last step, the closeness coefficient of each alternative ( $C$ ) was calculated using following Eq. 16.

$$C = \frac{d_i^-}{d_i^- + d_i^*} \tag{16}$$

Ranking of the alternatives was determined based on  $C$  values. Where  $C$  value is ranging from 0 to 1, and  $C$  value is closest to 1 implies that the  $i$ th option is the closest to the optimal level. Therefore, the sample with the highest  $C$  value was selected as the best alternative.

### Statistical analysis

Statistical analysis of the samples was performed by the SPSS statistics version 21.0 (SPSS, Chicago, Illinois, USA). All the experiments were performed three times and data were expressed as mean ± standard deviation. Differences between the samples produced with different concentration and treated with different homogenization pressure were determined by using one way analysis of variance (ANOVA) and multiple comparisons were performed by Duncan’s test with confidence level of 95% ( $P < 0.05$ ).

## Result and discussion

### Total solids, pH, water soluble matter (°Brix)

Total solids, pH and °Brix values of hazelnut milk samples produced from 5, 10 and 15% of hazelnut cakes and treated with high pressure homogenization at 40, 60, 80 and 100 MPa pressure are summarized in Table 1. Total solid values of homogenized samples at 5, 10 and 15% hazelnut concentration were not significantly different ( $P > 0.05$ ). pH values of samples decreased by the increasing the hazelnut concentration ( $P < 0.05$ ), but significant differences were not found after homogenization ( $P > 0.05$ ). In contrast to our findings, Bernat et al. [2] reported a slight increase

**Table 1** Physicochemical characteristics of hazelnut milks produced with different homogenizing pressures and three different concentrations

Con. (%)	Pressure (MPa)	Total solids (%)	pH	Water soluble matter ( $^{\circ}$ Brix)	Protein solubility (g/100 mL)
5	Untreated	4.93 $\pm$ 0.09 <sup>c</sup>	6.58 $\pm$ 0.01 <sup>a</sup>	3.21 $\pm$ 0.37 <sup>h</sup>	0.39 $\pm$ 0.16 <sup>h</sup>
	40	4.96 $\pm$ 0.06 <sup>c</sup>	6.57 $\pm$ 0.01 <sup>a</sup>	3.23 $\pm$ 0.18 <sup>h</sup>	0.81 $\pm$ 0.12 <sup>g</sup>
	60	4.88 $\pm$ 0.11 <sup>c</sup>	6.55 $\pm$ 0.02 <sup>a</sup>	3.5 $\pm$ 0.23 <sup>gh</sup>	0.96 $\pm$ 0.05 <sup>fg</sup>
	80	4.84 $\pm$ 0.12 <sup>c</sup>	6.57 $\pm$ 0.01 <sup>a</sup>	3.65 $\pm$ 0.35 <sup>gh</sup>	1.11 $\pm$ 0.02 <sup>fg</sup>
	100	4.85 $\pm$ 0.1 <sup>c</sup>	6.58 $\pm$ 0.01 <sup>a</sup>	3.78 $\pm$ 0.29 <sup>g</sup>	1.21 $\pm$ 0.02 <sup>f</sup>
10	Untreated	9.89 $\pm$ 0.1 <sup>b</sup>	6.48 $\pm$ 0.01 <sup>b</sup>	5.71 $\pm$ 0.58	2.91 $\pm$ 0.03 <sup>e</sup>
	40	9.88 $\pm$ 0.11 <sup>b</sup>	6.48 $\pm$ 0.01 <sup>b</sup>	5.6 $\pm$ 0.36 <sup>f</sup>	3.07 $\pm$ 0.03 <sup>e</sup>
	60	9.92 $\pm$ 0.1 <sup>b</sup>	6.45 $\pm$ 0.02 <sup>b</sup>	6.38 $\pm$ 0.12 <sup>e</sup>	3.04 $\pm$ 0.02 <sup>e</sup>
	80	9.87 $\pm$ 0.13 <sup>b</sup>	6.48 $\pm$ 0.01 <sup>b</sup>	6.78 $\pm$ 0.28 <sup>de</sup>	4.16 $\pm$ 0.11 <sup>d</sup>
	100	9.88 $\pm$ 0.1 <sup>b</sup>	6.48 $\pm$ 0.01 <sup>b</sup>	7.13 $\pm$ 0.54 <sup>cd</sup>	3.96 $\pm$ 0.04 <sup>d</sup>
15	Untreated	14.78 $\pm$ 0.15 <sup>a</sup>	6.41 $\pm$ 0.01 <sup>c</sup>	7.1 $\pm$ 0.07	4.13 $\pm$ 0.03 <sup>d</sup>
	40	14.81 $\pm$ 0.13 <sup>a</sup>	6.4 $\pm$ 0.02 <sup>c</sup>	7.63 $\pm$ 0.26 <sup>c</sup>	4.47 $\pm$ 0.05 <sup>cd</sup>
	60	14.8 $\pm$ 0.12 <sup>a</sup>	6.39 $\pm$ 0.01 <sup>c</sup>	7.98 $\pm$ 0.08 <sup>bc</sup>	5.31 $\pm$ 0.22 <sup>a</sup>
	80	14.93 $\pm$ 0.1 <sup>a</sup>	6.39 $\pm$ 0.02 <sup>c</sup>	8.43 $\pm$ 0.25 <sup>ab</sup>	4.92 $\pm$ 0.38 <sup>b</sup>
	100	14.88 $\pm$ 0.1 <sup>a</sup>	6.39 $\pm$ 0.01 <sup>c</sup>	8.68 $\pm$ 0.38 <sup>a</sup>	4.62 $\pm$ 0.32 <sup>bc</sup>

<sup>a–g</sup>Different letters in same column indicates significant differences between treatments in 95% of confidence ( $P < 0.05$ )

in pH values of hazelnut milk by homogenization process and explained this change by the conformational changes in components during homogenization which may inhibit the ionization of some acidic groups. Dhakal et al. [15] reported that a transient change in pH of food and buffer solutions could be observed during high pressure homogenization due to change in dissociation constant of attendant acids and bases. As expected,  $^{\circ}$ Brix values of the hazelnut milk samples increased after the homogenization treatment but it was not statistically important at 5% hazelnut concentration. Homogenization pressure at 100 MPa ensured to increase the water soluble matter at 7.13 and 8.68 as  $^{\circ}$ Brix for 10 and 15% concentration levels, respectively. This may be explained by the increase in soluble protein ratio during high pressure homogenization (Table 1). Moreover, starch content of hazelnut ranged from 8.27 to 20.09 g/kg dry weight and for Tombul cultivar from Turkey was detected as 12.45 g/kg dry weight [24]. Therefore, the increase in  $^{\circ}$ Brix may be result of the release of starch granules upon mechanical stress during high pressure homogenization process and eventually increasing the extent of starch gelatinization and solubilization [14].

### Particle size distribution

Determination of particle size distribution is an important aspect because it is related to sensory properties and the power of homogenization process. Particle size of all untreated hazelnut milk samples showed a bimodal particle size distribution and typically extended from 114.99 to 124.72  $\mu$ m (Table 2). This result was in agreement with the

previous observation for hazelnut milk and raw almond milk [2, 25] due to the complex composition and preparation process. It is expected that particle size of samples homogenized at different pressures (40–100 MPa) was decreased by the pressure, but particle size distribution of homogenized samples had limited ranges due to the fragmentation of bigger particles and reduction of plant cell remains. The increase in homogenization pressure caused a significant decline at the average particle diameter as a result of the various forces induced in the microfluidizer [26]. The volume-weighted mean diameters ( $D_{4,3}$ ) and the surface-weighted mean diameter ( $D_{3,2}$ ) of untreated hazelnut milks were in the range of 153.53–172.08 and 24.49–29.15  $\mu$ m, respectively depending on the hazelnut concentration. The high-pressure homogenization process significantly decreased the  $D_{4,3}$  and  $D_{3,2}$  values ( $P < 0.05$ ). The changes in  $D_{4,3}$  and  $D_{3,2}$  values of homogenized hazelnut milk samples were more pronounced at 100 MPa for all concentrations. Moreover, the decrease rate of  $D_{4,3}$  value (70.87–75.95%) were higher than that of  $D_{3,2}$  (30.42–44.29%). This may be explained that smaller suspended particles are less sensitive to breakage during high pressure homogenization compared to the bigger ones [14]. Because, while  $D_{4,3}$  value is more affected by large particles,  $D_{3,2}$  value is greatly affected by smaller ones [27].

According to Tan and Nakajima [26], the span index expressed width of the particles size distribution as described in the British Standard. In our study, span values were determined between 3.18 and 3.23 and there was a slight decrease as the hazelnut concentration increased. The span values of the samples significantly decreased due to the homogenization process ( $P < 0.05$ ). Hazelnut milk produced

**Table 2** Characteristics of particle size of hazelnut milks produced with different homogenizing pressures and three different concentrations

Con. (%)	Pressure (MPa)	$D_{4,3}$ ( $\mu\text{m}$ )	$D_{3,2}$ ( $\mu\text{m}$ )	$d_{50}$ ( $\mu\text{m}$ )	Span value
5	Untreated	$153.53 \pm 3.74^c$	$24.49 \pm 1.04^{bc}$	$114.99 \pm 1.79^b$	$3.18 \pm 0.07^a$
	40	$63.87 \pm 1.39^e$	$18.43 \pm 0.82^{fgh}$	$56.17 \pm 1.94^d$	$2.21 \pm 0.08^{bc}$
	60	$56.26 \pm 0.96^f$	$18.23 \pm 0.77^{efg}$	$51.31 \pm 1.24^e$	$2.11 \pm 0.02^{bcd}$
	80	$53.05 \pm 0.38^{fg}$	$17.85 \pm 1.42^{fgh}$	$46.01 \pm 1.45^{fg}$	$2.14 \pm 0.06^{bcd}$
	100	$44.72 \pm 6.35^{hi}$	$17.04 \pm 0.76^{gh}$	$38.92 \pm 1.34^h$	$2.01 \pm 0.01^{cd}$
10	Untreated	$158.16 \pm 4.98^b$	$26.59 \pm 1.23^{ab}$	$117.18 \pm 1.13^b$	$3.21 \pm 0.10^a$
	40	$70.02 \pm 1.84^d$	$20.84 \pm 4.35^{ef}$	$63.12 \pm 2.10^c$	$2.15 \pm 0.1^{bcd}$
	60	$55.08 \pm 1.82^f$	$20.14 \pm 1.42^{de}$	$51.34 \pm 2.13^e$	$2.17 \pm 0.09^{bcd}$
	80	$48.3 \pm 3.03^h$	$19.91 \pm 2.24^{efg}$	$42.36 \pm 2.15^{fgh}$	$2.33 \pm 0.2^b$
	100	$42.59 \pm 1.16^i$	$18.25 \pm 1.46^{fgh}$	$38.78 \pm 0.56^h$	$2.12 \pm 0.12^{bc}$
15	Untreated	$172.08 \pm 1.9^{2a}$	$29.15 \pm 1.30^a$	$124.72 \pm 1.68^a$	$3.23 \pm 0.06^a$
	40	$61.72 \pm 1.21^e$	$22.46 \pm 1.19^{cd}$	$57.39 \pm 0.87^d$	$1.97 \pm 0.11^d$
	60	$54.95 \pm 0.75^f$	$19.88 \pm 0.34^{efg}$	$46.77 \pm 1.53^f$	$2.01 \pm 0.15^{bc}$
	80	$48.83 \pm 0.59^{gh}$	$16.89 \pm 1.54^h$	$44.53 \pm 1.56^{fg}$	$1.96 \pm 0.14^d$
	100	$41.4 \pm 1.9^i$	$16.24 \pm 1.11^h$	$41.95 \pm 6.2^{sh}$	$1.97 \pm 0.24^d$

$D_{4,3}$  volume-weighted mean diameter,  $D_{3,2}$  surface-weighted mean diameter,  $d_{50}$  average particle size at 50% of the volume of particles

<sup>a-i</sup>Different letters in same column indicates significant differences between treatments in 95% of confidence (P < 0.05)

**Table 3** Rheological parameters of hazelnut milks produced with different homogenizing pressures and three different concentrations

Con. (%)	Pressure (MPa)	$n$	$K$ (Pa.s <sup>n</sup> )	$R^2$	$D_{app}$ (Pa.s)
5	Untreated	$0.059 \pm 0.03$	$44.774 \pm 18.69$	0.91	$0.461 \pm 0.216^{ef}$
	40	$0.258 \pm 0.07$	$0.096 \pm 0.025$	0.954	$0.004 \pm 0.001^h$
	60	$0.372 \pm 0.1$	$0.091 \pm 0.047$	0.978	$0.006 \pm 0.001^h$
	80	$0.388 \pm 0.02$	$0.049 \pm 0.001$	0.980	$0.006 \pm 0.001^h$
	100	$0.448 \pm 0.05$	$0.064 \pm 0.031$	0.968	$0.007 \pm 0.002^h$
10	Untreated	$0.153 \pm 0.057$	$82.838 \pm 22.653$	0.998	$0.923 \pm 0.178^c$
	40	$0.234 \pm 0.021$	$2.671 \pm 0.399$	0.996	$0.214 \pm 0.148^f$
	60	$0.28 \pm 0.06$	$0.914 \pm 0.281$	0.995	$0.056 \pm 0.009^g$
	80	$0.27 \pm 0.085$	$0.873 \pm 0.423$	0.995	$0.047 \pm 0.011^g$
	100	$0.346 \pm 0.001$	$0.481 \pm 0.059$	0.998	$0.038 \pm 0.005^g$
15	Untreated	$0.101 \pm 0.003$	$284.02 \pm 46.83$	0.995	$2.03 \pm 0.067^a$
	40	$0.148 \pm 0.017$	$49.17 \pm 10.78$	0.999	$1.237 \pm 0.07^b$
	60	$0.099 \pm 0.002$	$38.68 \pm 4.47$	0.996	$1.014 \pm 0.009^c$
	80	$0.068 \pm 0.045$	$27.1 \pm 2.37$	0.996	$0.715 \pm 0.107^{dc}$
	100	$0.048 \pm 0.023$	$21.088 \pm 5.177$	0.998	$0.532 \pm 0.014^e$

$n$  flow behavior index (dimensionless),  $K$  consistency index,  $\eta_{app}$  apparent viscosity

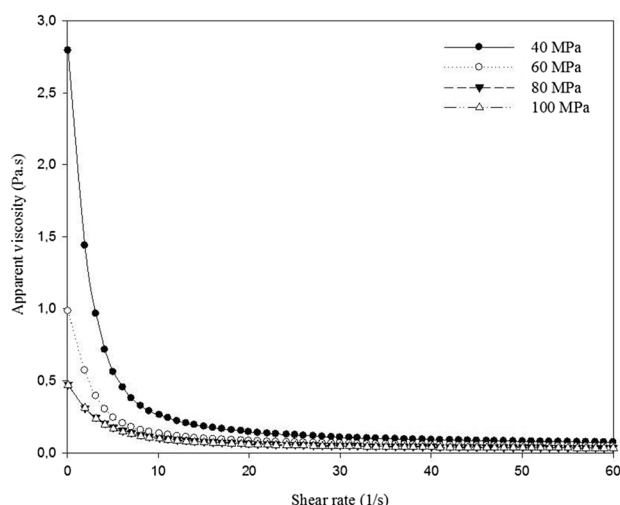
<sup>a-g</sup>Different letters in same column indicates significant differences between treatments in 95% of confidence (P < 0.05)

with 15% hazelnut concentration showed a small span value for all homogenization pressures. A small span value indicates a narrow particle size distribution [26].

### Rheological measurements

The rheological parameters ( $K$ ,  $n$ , and  $D_{app}$ ) of untreated and homogenized samples are shown in Table 3 and the

viscosity of hazelnut milk samples (10% of concentration) treated with different homogenization pressure as a function of shear rate was graphically shown in Fig. 1. According to correlation coefficient values ( $R^2 = 0.954-0.999$ ), Ostwald de Waele model was found suitable for modeling of hazelnut milks rheological properties. Apparent viscosity was selected at a shear rate of  $50 \text{ s}^{-1}$  which gives the best mouth-sense of samples. The flow behavior index ( $n$ ) of all



**Fig. 1** The flow behavior of hazelnut milk samples (10% of concentration) treated with different homogenization pressure

samples were lower than 1 that means all samples show non-Newtonian and shear thinning behavior. However, Bernat et al. [2] found that untreated hazelnut milk samples produced with 8% hazelnut contained 0.65% of protein showed Newtonian behavior.

When the homogenization process was applied to all untreated samples, it is clear that viscosity and consistency index values decreased sharply ( $P < 0.05$ ). This may be attributed to the breakages of protein chains and loss of water-binding capability of proteins by high pressure effect. Among the treated hazelnut milk samples, effect of homogenization process on viscosity values of the samples could not be perceived at the lowest concentration (5%) ( $P > 0.05$ ). However, at the 10 and 15% concentrations, the increase in homogenization pressure was lead to decrease in viscosities of the treated samples due to higher protein concentration of samples ( $P < 0.05$ ). Similarly, Augusto et al. [28] reported that falling tendency of viscosity was observed with homogenization process. However, Bernat et al. [2] stated that homogenized hazelnut milk samples showed greater apparent viscosity than that of the untreated samples.

Harte and Venegas [29] suggested an exponential function for describe the effect of high pressure homogenization at various pressures and homogenization cycles on the viscosity of polymer suspensions (Eq. 17).

$$n_{(mPa.s)} = n_0 \left( \frac{k_1 + e^{-k_2 \cdot n \cdot P_H}}{k_1 + 1} \right) \quad (17)$$

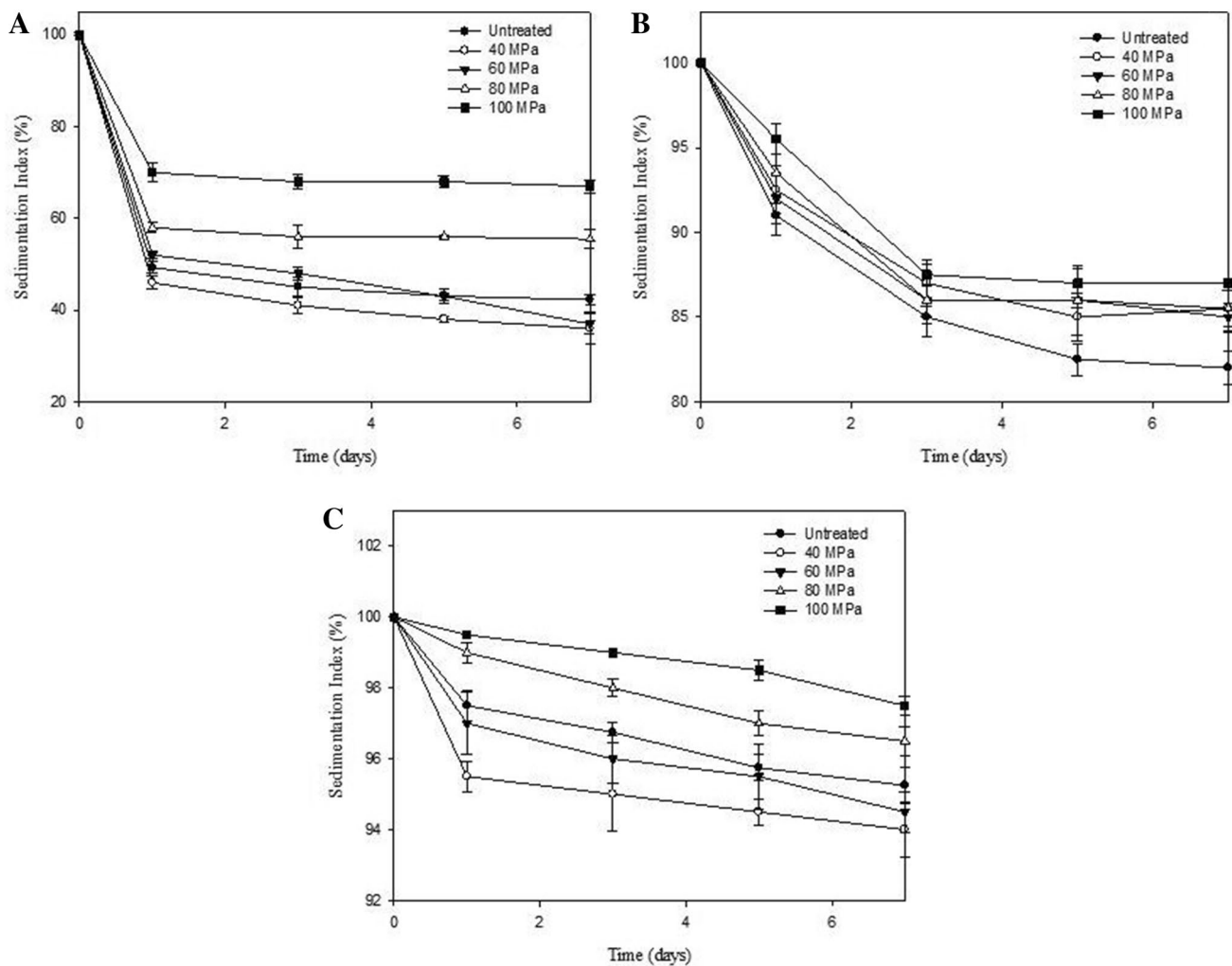
where  $n_{(mPa.s)}$  is the predicted viscosity (mPa.s) after homogenization process at different pressure  $p$  ( $P = 0$  to 300 MPa),  $n_0$  is the viscosity (mPa.s) for untreated samples,  $n$  is the number of homogenization cycles ( $n = 0, 1, 2,$

3, 4, 5),  $P_H$  is the homogenization pressure,  $k_1$  and  $k_2$  are constant that determines the plateau viscosity after homogenization pressure or number of homogenization cycle and initial exponential decay in viscosity due to homogenization, respectively.

The equation well explains the reduction in viscosity due to the homogenization pressure in the hazelnut milk prepared at 10 and 15% hazelnut concentration. The  $k_1$  and  $k_2$  parameters for the model were determined as 0.0066 and 0.0396 for 10% hazelnut milk and  $-0.1864$  and 0.0092 for 15% hazelnut milk, respectively and high correlation coefficient ( $R^2 > 0.996$ ) between experimental and predictive viscosity was calculated. For all concentrations, being  $k_2$  values higher than  $k_1$  values shows that there is a rapid initial reduction in viscosity due to pressure [29].

### Colloidal stability

From Fig. 2, the sedimentation index values of hazelnut milk samples were significantly influenced by hazelnut concentration and homogenization treatment ( $P < 0.05$ ). After 7 days of storage, there was notable difference in the heights of separate phases for all samples. Therefore, the phase separation of milk samples was evaluated throughout 7 days at 4 °C. Sedimentation index was determined between 38 and 95.25% for untreated hazelnut milk samples at the end of storage time. Increasing hazelnut concentration caused a positive effect on sedimentation index due to water holding capacity of proteins and stabilizing fat globules as expected. It was found that homogenization positively affected the phase separation for all concentration ( $P < 0.05$ ). Similar result was reported by Yu et al. [14] who found that high pressure homogenization up to 30 MPa progressively reduced the sedimentation velocity of dispersed particles and improved the suspension stability of taro pulp. In our study, increasing homogenization pressure (80 and 100 MPa) decreased the phase separation for the 5% hazelnut samples ( $P < 0.05$ ), except at lower homogenization pressure (up to 60 MPa). Similar reduction was observed for the 10% hazelnut samples but this reduction was not significantly different for homogenized samples ( $P > 0.05$ ). At the higher concentration (%15), suspension stability of untreated hazelnut milk was better although phase separation was decreased by the increase in homogenization pressure. This might be explained by the fact that high protein content of 15% concentration of hazelnut milk may cause an increase in phase separation. Homogenization pressure could cause the separation of phases due to enhancing protein–protein interactions and allowing a higher aggregation of these proteins [14]. Moreover, increasing denaturation degree of serum proteins by higher pressure values can show tackling effect on phase separation [2].



**Fig. 2** Pulp sedimentation index (%) of hazelnut milks produced with different homogenizing pressures and three different concentrations during storage. **a** Hazelnut milk with 5% concentration; **b** hazelnut milk with 10% concentration; **c** hazelnut milk with 15% concentration

### Protein solubility

Protein solubility contents of untreated hazelnut milk samples were determined as 0.39, 2.91 and 4.13 g/100 mL for 5, 10, and 15% hazelnut cake concentration, respectively (Table 1). The protein solubility of hazelnut milk was significantly increased by homogenization process ( $P < 0.05$ ). However, it was decreased with increase in homogenization pressure from 80 to 100 MPa, except samples with 5% hazelnut concentration. Similarly, Dhakal et al. [15] reported that protein solubility in almond milk was slightly increased when low pressure used due to improved protein solvation as a result of deprotonation of polar amino acids during process. In contrast, Qin et al. [30] found that solubility of walnut protein isolate decreased with the increase of the applied pressure. The high pressure homogenization may cause to disrupt the protein structure due to distortion in their secondary, tertiary, and quaternary structure(s) and consequently

may lead to protein aggregation and/or precipitation resulting decrease in protein solubility [15].

### Color properties

Color properties ( $L^*$ : lightness,  $a^*$ : redness and  $b^*$ : yellowness) of untreated and homogenized hazelnut milk samples with the chrome ( $C^*_{ab}$ ), hue ( $h^*_{ab}$ ), white index ( $WI$ ) and color difference ( $\Delta E$ ) between untreated and homogenized samples are shown in Table 4. High pressure homogenization process caused an increase in  $L^*$  values for all and homogenized samples looked brighter than untreated hazelnut milk samples. Moreover,  $b^*$  values of homogenized samples decreased compare to the untreated samples. No significance difference of the  $a^*$  values was observed between homogenized and untreated samples. These results were similar with previous findings by Yu et al. [14] with taro pulp, Bernat et al. [2] with walnut and hazelnut milk,

**Table 4** Color properties of hazelnut milks produced with different homogenizing pressures and three different concentrations

Con. (%)	Pressure (MPa)	$L^*$	$a^*$	$b^*$	$\Delta E$	$C^*_{ab}$	$h^*_{ab}$	WI
5	Untreated	78.69 ± 0.83 <sup>c</sup>	0.33 ± 0.25 <sup>d</sup>	12.13 ± 0.49 <sup>c</sup>	–	12.13 ± 0.49 <sup>d</sup>	1.54 ± 0.02 <sup>b</sup>	75.48 ± 0.8 <sup>c</sup>
	40	79.07 ± 0.09 <sup>c</sup>	0.11 ± 0.14 <sup>e</sup>	10.76 ± 0.14 <sup>d</sup>	1.63 ± 0.34 <sup>a</sup>	10.76 ± 0.14 <sup>e</sup>	1.55 ± 0.8 <sup>a</sup>	76.46 ± 0.12 <sup>cb</sup>
	60	79.29 ± 0.54 <sup>c</sup>	0.13 ± 0.04 <sup>e</sup>	10.77 ± 0.18 <sup>d</sup>	1.81 ± 0.69 <sup>a</sup>	10.77 ± 0.18 <sup>e</sup>	1.55 ± 0.01 <sup>a</sup>	76.66 ± 0.55 <sup>cb</sup>
	80	79.67 ± 0.69 <sup>bc</sup>	0.03 ± 0.08 <sup>e</sup>	10.23 ± 0.38 <sup>d</sup>	2.19 ± 0.66 <sup>a</sup>	10.23 ± 0.38 <sup>e</sup>	1.56 ± 0.8 <sup>a</sup>	77.24 ± 0.78 <sup>ab</sup>
	100	79.85 ± 0.49 <sup>b</sup>	0.07 ± 0.15 <sup>e</sup>	10.31 ± 0.34 <sup>d</sup>	2.28 ± 0.52 <sup>a</sup>	10.31 ± 0.34 <sup>e</sup>	1.56 ± 0.79 <sup>a</sup>	77.10 ± 0.59 <sup>ab</sup>
10	Untreated	80.02 ± 1.13 <sup>ba</sup>	1.08 ± 0.16 <sup>c</sup>	13.09 ± 0.49 <sup>b</sup>	–	13.14 ± 0.5 <sup>bc</sup>	1.49 ± 0.01 <sup>c</sup>	76.92 ± 1.22 <sup>cb</sup>
	40	80.51 ± 0.46 <sup>ab</sup>	0.98 ± 0.09 <sup>c</sup>	12.52 ± 0.39 <sup>bc</sup>	1.11 ± 0.81 <sup>a</sup>	12.56 ± 0.4 <sup>cd</sup>	1.49 ± 0.01 <sup>c</sup>	77.65 ± 0.61 <sup>ab</sup>
	60	81.01 ± 0.62 <sup>a</sup>	1.01 ± 0.03 <sup>c</sup>	12.56 ± 0.23 <sup>bc</sup>	1.14 ± 0.59 <sup>a</sup>	12.6 ± 0.23 <sup>bcd</sup>	1.49 ± 0.01 <sup>c</sup>	77.43 ± 0.63 <sup>ab</sup>
	80	81.28 ± 0.51 <sup>a</sup>	1.01 ± 0.4 <sup>c</sup>	12.57 ± 0.23 <sup>bc</sup>	1.18 ± 0.5 <sup>a</sup>	12.61 ± 0.23 <sup>bcd</sup>	1.49 ± 0.01 <sup>c</sup>	77.21 ± 0.54 <sup>ab</sup>
	100	80.84 ± 0.58 <sup>ab</sup>	1.01 ± 0.1 <sup>c</sup>	12.71 ± 0.22 <sup>bc</sup>	1.2 ± 0.52 <sup>a</sup>	12.75 ± 0.22 <sup>bc</sup>	1.49 ± 0.01 <sup>c</sup>	76.99 ± 0.53 <sup>ab</sup>
15	Untreated	81.84 ± 1.03 <sup>a</sup>	1.53 ± 0.15 <sup>a</sup>	14.21 ± 0.49 <sup>a</sup>	–	14.20 ± 0.49 <sup>a</sup>	1.46 ± 0.01 <sup>d</sup>	76.15 ± 1.11 <sup>c</sup>
	40	82.28 ± 0.71 <sup>a</sup>	1.25 ± 0.05 <sup>b</sup>	12.74 ± 0.23 <sup>b</sup>	2.1 ± 1.69 <sup>a</sup>	12.8 ± 0.24 <sup>bc</sup>	1.47 ± 0.01 <sup>d</sup>	78.14 ± 0.71 <sup>a</sup>
	60	82.91 ± 1.12 <sup>a</sup>	1.3 ± 0.05 <sup>b</sup>	12.94 ± 0.29 <sup>b</sup>	2.11 ± 1.13 <sup>a</sup>	13 ± 0.29 <sup>bc</sup>	1.47 ± 0.01 <sup>d</sup>	77.72 ± 1.08 <sup>ab</sup>
	80	82.94 ± 1.05 <sup>a</sup>	1.31 ± 0.05 <sup>b</sup>	12.99 ± 0.27 <sup>b</sup>	2.16 ± 0.98 <sup>a</sup>	13.05 ± 0.28 <sup>bc</sup>	1.47 ± 0.01 <sup>d</sup>	77.71 ± 1.01 <sup>ab</sup>
	100	82.95 ± 0.79 <sup>a</sup>	1.35 ± 0.01 <sup>b</sup>	13.15 ± 0.11 <sup>b</sup>	2.18 ± 1.12 <sup>a</sup>	13.22 ± 0.12 <sup>b</sup>	1.47 ± 0.01 <sup>d</sup>	77.89 ± 0.72 <sup>ab</sup>

$\Delta E$  Color difference,  $C^*_{ab}$  Chrome,  $h^*_{ab}$  Hue, WI whiteness index

<sup>a–e</sup>Different letters in same column indicates significant differences between treatments in 95% of confidence ( $P < 0.05$ )

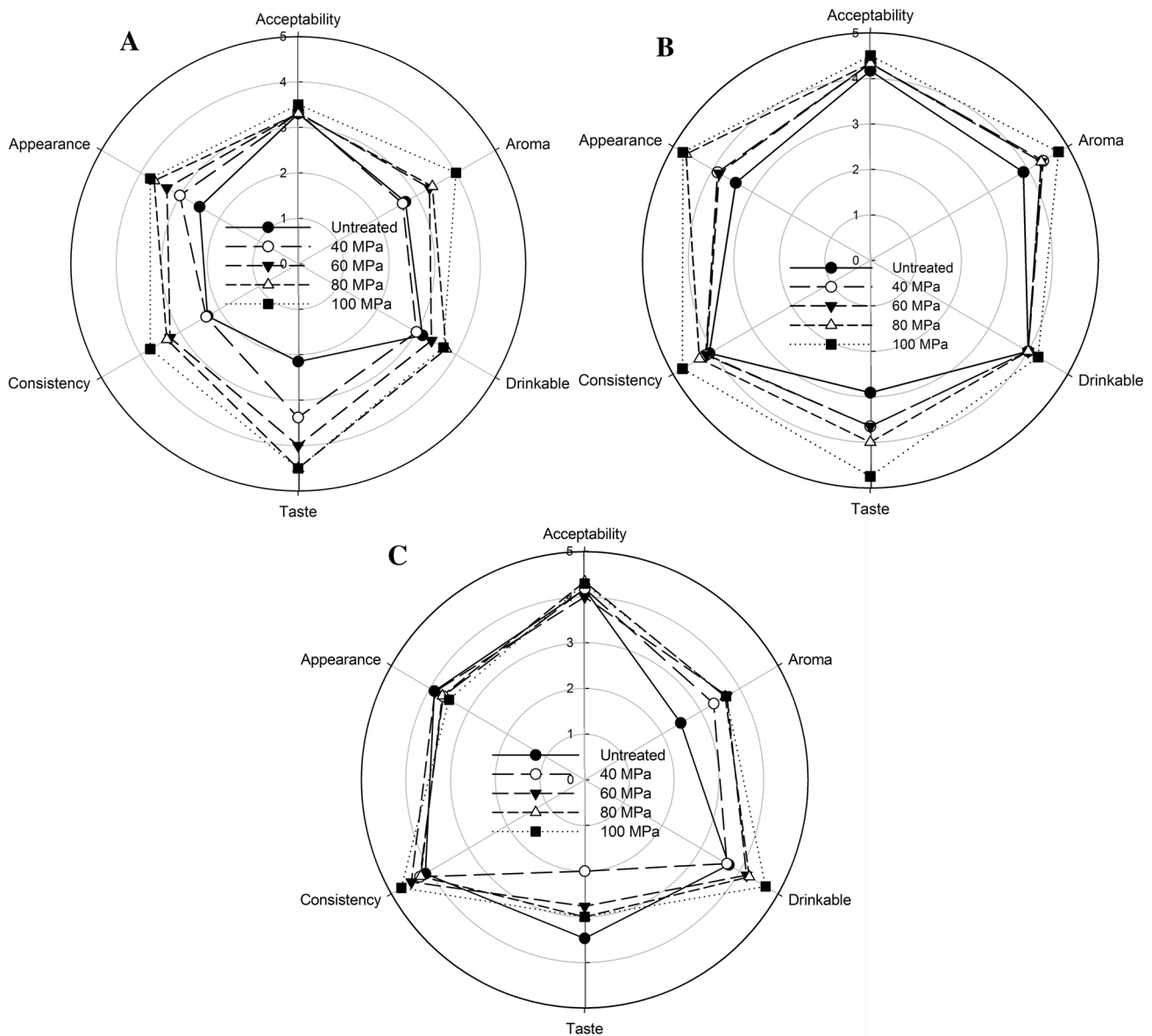
and Betoret et al. [31] with orange juice, they stated that lightness significantly increased due to the homogenization process. Yu et al. [14] reported that the particle distribution and subsequent fragmentation caused by high pressure homogenization would cause an increase in the lightness of samples because of smaller particles have a higher ability to scatter light. Additionally, the increase in the number of particle after the homogenization could be contributed to the light reflection [2].

An increase in  $C^*_{ab}$  and WI values of milk samples treated with homogenization was observed ( $P < 0.05$ ), however  $h^*_{ab}$  value slightly decreased ( $P > 0.05$ ). The  $\Delta E$  values of homogenized samples increased with the increase in homogenization pressure but this was not significant ( $P > 0.05$ ). The difference in color relation of the sample  $\Delta E$  is classified as not noticeable (0–0.5), slightly noticeable (0.5–1.5), noticeable (1.5–3.0), well visible (3.0–6.0) and great (6.0–12.0) [32]. Hazelnut milk samples homogenized from 40 to 100 MPa exhibited slightly noticeable and noticeable variation in color for 10 and 5–15% hazelnut concentration, respectively. Additionally,  $\Delta E$  values were found lower than 3 which expressed the no detected by human eye [2].

## Sensory analysis

Sensory evaluation of hazelnut milk samples at different homogenization pressures is shown in Fig. 3. Appearances of hazelnut milk samples were better at higher homogenization pressures. It is accordance with color properties of homogenized samples as shown in Table 2. When the pressure of homogenization treatment was adjusted at

100 MPa, physical properties of hazelnut milks with 10 and 15% concentrations were rated better. Consistency of 5 and 10% hazelnut milks was better as homogenization pressure increased, but this trend was not observed for the samples at 15% hazelnut concentration. In addition, the panelists stated that the consistency of 15% hazelnut milk decreased with the pressure increased. Taste and aroma characteristics of hazelnut milk samples except 5% were not significantly different based on pressure and this may be explained that panelists preferred 10 and 15% samples in terms of taste and aroma. Moreover, increasing pressure had a positive effect on taste and aroma properties at 5% concentration. It is clear that pressure has an important effect on drinking properties of hazelnut milk samples. Furthermore, drinkable properties of hazelnut milk samples at 5 and 10% ratio were higher than that of 15% and application of 100 MPa homogenization pressure to hazelnut milks affected drinkable properties of the samples, except 15% concentration. Although homogenization treatment did not have a significant effect on preference of the 5 and 10% concentration of hazelnut milk, applying an increased homogenization pressure to 15% hazelnut milk samples caused a positive effect on aroma preferences of samples. All of the homogenization pressure applications to the 10% hazelnut milk samples have higher general acceptability than the others and the panelists stated that 10% hazelnut milk homogenized at 100 MPa was similar to cow's milk. In addition, 100 MPa homogenization pressure had a positive effect on general acceptability for hazelnut milk samples. It can be concluded that homogenization treatment is a critical treatment for the final product preference because of decreasing grittiness sensation. Even



**Fig. 3** Sensory properties of hazelnut milks produced with different homogenizing pressures and three different concentrations. **a** Hazelnut milk with 5% concentration; **b** hazelnut milk with 10% concentration; **c** hazelnut milk with 15% concentration

though sensory evaluation scores of hazelnut milk samples at 15% concentration were higher as the homogenization pressure increased, they had a gritty sensation.

### TOPSIS approach for determine the best parameters

In the present study, physicochemical properties, physical stability and sensory characteristics of hazelnut milk produced from cold press hazelnut cake were significantly affected by both hazelnut cake concentration and homogenization pressure. However, decision making for ideal concentration and homogenization pressure is difficult because of the best milk properties varied depending on the different

criteria studied. Therefore, TOPSIS approach was applied for decision making to tackle multi criteria decision problems and this method allows finding the best alternative. As seen in Table 5, the various distances were calculated using Eqs. 14 and 15 which indicate the position of different alternatives for each factor from positive and negative ideal solutions. These distances were used for calculation of relative closeness (C values). Based upon Table 5, the best alternative (0.86026) had the nearest distance to the positive ideal (0.1911) and also the farthest distance to the negative ideal (0.1177). According to the final rankings of hazelnut milks, 10% of hazelnut cake concentration and 100 MPa of homogenization pressure for manufacture of hazelnut milk

**Table 5** Final rankings of hazelnut milks obtained by the TOPSIS approach on different hazelnut cake concentration and homogenization pressure

Rank	Concentration (%)	Pressure (MPa)	$d_i^+$	$d_i^-$	$C$
1	10	100	0.01911	0.11770	0.86026
2	10	80	0.01956	0.11538	0.85499
3	10	60	0.03340	0.10933	0.76595
4	10	40	0.04225	0.09770	0.69807
5	15	100	0.04995	0.08818	0.63835
6	5	100	0.06144	0.10576	0.63254
7	5	80	0.06673	0.10248	0.60561
8	5	60	0.07194	0.10152	0.58528
9	5	40	0.07809	0.10094	0.56382
10	15	80	0.06296	0.08043	0.56092
11	15	60	0.0856	0.07280	0.45956
12	15	40	0.10568	0.05952	0.36029

$d_i^+$  distance of positive ideal solution,  $d_i^-$  distance of negative ideal solution,  $C$  closeness coefficient

was the best condition due to the highest  $C$  value obtained when used this conditions. This result attributed to sensory properties due to the highest general acceptability score (4.77) of hazelnut milk and also the lower average particle size (38.78  $\mu\text{m}$ ) was obtained when used 10% of hazelnut cake concentration and 100 MPa of homogenization pressure. On the other hand, the hazelnut milk produced with 15% of hazelnut cake concentration and 40 MPa of homogenization pressure, which is located in the last position by the TOPSIS approach, gets the lowest ranking because this sample had the highest viscosity (1.237 Pa.s) and average particle size (57.39  $\mu\text{m}$ ) and according to Table 5 it's distance to the positive and negative ideal were 0.10568 and 0.05952, respectively.

## Conclusion

The aim of the present work was to evaluate the effect of cold pressed hazelnut cake concentration and high pressure homogenization on the physicochemical, rheological and microstructural properties of cold pressed hazelnut cake milk. Concentration and high pressure homogenization significantly affected the physical properties and stability and chemical properties of hazelnut milk. Increasing concentration and homogenization pressure improved the syneresis, pulp sedimentation index and sensory properties of hazelnut milks. According to TOPSIS approach, 10% of hazelnut cake concentration and 100 MPa homogenization pressure were the best parameters for hazelnut milk production. There has been a limited study about the production

and standardization of hazelnut milk from hazelnut. So that, this research may lead the way of hazelnut milk production from cold pressed hazelnut cake as waste recycling. Further work is needed to conclude the different parameters such as heat treatment and storage time for production of hazelnut milk and the improved the quality of hazelnut milk from cold pressed hazelnut cake.

**Acknowledgements** The authors acknowledge financial support provided by Turkish Scientific and Technical Research Council (TUBITAK) for the project (Project Number: TOVAG 1140174).

## References

1. K. Kurajdová, J. Táborecká-Petrovičová, A. Kaščáková, Factors influencing milk consumption and purchase behavior—evidence from Slovakia. *Proc. Econ. Financ.* **34**, 573–580 (2015)
2. N. Bernat et al., Effect of high pressure homogenisation and heat treatment on physical properties and stability of almond and hazelnut milks. *LWT Food Sci. Technol.* **62**(1), 488–496 (2015)
3. A. Fiocchi et al., Diagnosis and rationale for action against cow's milk allergy (DRACMA): a summary report. *J. Allergy Clin Immunol* **126**(6), 1119–1128 (2010)
4. D.C. Valencia-Flores et al., Comparing the effects of ultra-high-pressure homogenization and conventional thermal treatments on the microbiological, physical, and chemical quality of almond beverages. *J. Food Sci.* **78**(2), E199–E205 (2013)
5. A.J. Esfahlan, R. Jamei, R.J. Esfahlan, The importance of almond (*Prunus amygdalus* L.) and its by-products. *Food Chem.* **120**(2), 349–360 (2010)
6. N. Bernat et al., Vegetable milks and their fermented derivative products. *Int. J. Food Stud.* **3**, 93–124 (2014)
7. I. Oliveira et al., Chemical composition, and antioxidant and antimicrobial activities of three hazelnut (*Corylus avellana* L.) cultivars. *Food Chem. Toxicol.* **46**(5), 1801–1807 (2008)
8. C. Alasalvar, S.J. Amaral, F. Shahidi, Functional lipid characteristics of Turkish tombul hazelnut (*Corylus avellana* L.). *J. Agric. Food Chem.* **54**, 10177–10183 (2006)
9. C. Alasalvar et al., Turkish tombul hazelnut (*Corylus avellana* L.). 1. Compositional characteristics. *J. Agric. Food Chem.* **51**, 3790–3796 (2003)
10. J. Flourey, A. Desrumaux, J. Lardieres, Effect of high-pressure homogenization on droplet size distributions and rheological properties of model oil-in-water emulsions. *Innov. Food Sci. Emerg. Technol.* **1**(2), 127–134 (2000)
11. A. Desrumaux, J. Marcand, Formation of sunflower oil emulsions stabilized by whey proteins with high-pressure homogenization (up to 350 MPa): effect of pressure on emulsion characteristics. *Int. J. Food Sci. Technol.* **37**(3), 263–269 (2002)
12. N. Datta et al., Significance of frictional heating for effects of high pressure homogenisation on milk. *J. Dairy Res.* **72**(4), 393–399 (2005)
13. A.M. Diels et al., Inactivation of *Escherichia coli* by high-pressure homogenisation is influenced by fluid viscosity but not by water activity and product composition. *Int. J. Food Microbiol.* **101**(3), 281–291 (2005)
14. Z.Y. Yu et al., Effect of high pressure homogenization (HPH) on the physical properties of taro (*Colocasia esculenta* (L.) Schott) pulp. *J. Food Eng.* **177**, 1–8 (2016)
15. S. Dhakal et al., Effect of high pressure processing on the immunoreactivity of almond milk. *Food Res. Int.* **62**, 215–222 (2014)

16. N. Cruz et al., Ultra high pressure homogenization of soymilk: Microbiological, physicochemical and microstructural characteristics. *Food Res. Int.* **40**(6), 725–732 (2007)
17. Y. Chen et al., Stable mixed beverage is produced from walnut milk and raw soymilk by homogenization with subsequent heating. *Food Sci. Technol. Res.* **20**(3), 583–591 (2014)
18. AOAC, in *Official Methods of Analysis, 16th ed.* (Association of Analytical Chemists, Arlington, 1995)
19. M.T.K. Kubo, P.E.D. Augusto, M. Cristianini, Effect of high pressure homogenization (HPH) on the physical stability of tomato juice. *Food Res. Int.* **51**(1), 170–179 (2013)
20. H.W. Robinson, C.G. Hogden, The biuret reaction in the determination of serum proteins. 2. Measurements made by a Duboscq colorimeter compared with values obtained by the Kjeldahl procedure. *J. Biol. Chem.* **135**, 727–731 (1940)
21. S. Ballı, S. Korukoğlu, Operating system selection using fuzzy ahp and topsis methods. *Math. Comput. Appl.* **14**(2), 119–130 (2009)
22. S. Karaman et al., Physicochemical, bioactive, and sensory properties of persimmon-based ice cream: technique for order preference by similarity to ideal solution to determine optimum concentration. *J. Dairy Sci.* **97**(1), 97–110 (2014)
23. V.E. Gurmeric et al., Application of different multi-criteria decision techniques to determine optimum flavour of prebiotic pudding based on sensory analyses. *Food Bioprocess Technol.* **6**(10), 2844–2859 (2012)
24. V. Cristofori et al., Nut and kernel traits and chemical composition of hazelnut (*Corylus avellana* L.) cultivars. *J. Sci. Food Agric.* **88**(6), 1091–1098 (2008)
25. K. Briviba et al., Ultra high pressure homogenization of almond milk: Physico-chemical and physiological effects. *Food Chem.* **192**, 82–89 (2016)
26. C. Tan, M. Nakajima,  $\beta$ -Carotene nanodispersions: preparation, characterization and stability evaluation. *Food Chem.* **92**(4), 661–671 (2005)
27. H. Bengtsson, E.V.A. Tornberg, Physicochemical characterization of fruit and vegetable fiber suspensions. I: effect of homogenization. *J. Texture Stud.* **42**(4), 268–280 (2011)
28. P.E.D. Augusto, A. Ibarz, M. Cristianini, Effect of high pressure homogenization (HPH) on the rheological properties of a fruit juice serum model. *J. Food Eng.* **111**(2), 474–477 (2012)
29. F. Harte, R. Venegas, A model for viscosity reduction in polysaccharides subjected to high-pressure homogenization. *J. Texture Stud.* **41**(1), 49–61 (2010)
30. Z. Qin et al., Effects of high hydrostatic pressure on physicochemical and functional properties of walnut (*Juglans regia* L.) protein isolate. *J. Sci. Food Agric.* **93**(5), 1105–1111 (2013)
31. E. Betoret et al., Effects of pressure homogenization on particle size and the functional properties of citrus juices. *J. Food Eng.* **92**(1), 18–23 (2009)
32. Z. Cserhalmi et al., Study of pulsed electric field treated citrus juices. *Innov. Food Sci. Emerg. Technol.* **7**(1–2), 49–54 (2006)