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The stages of candied chestnut production and the influence of the sorbitol used on their properties

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RESEARCH ARTICLE

Abstract

Chestnut is a healthy and valuable food and it can be consumed in many different forms, such as fresh, boiled, roasted and also candied. The aim of this study was to examine the changes take place in all stages of candied chestnut production and the possibility of using sorbitol as a sugar substitute from a health perspective, as well. The obtained results ensured the detailed information in paring, boiling and sugar-dipping production processes and the determination of chestnut properties in them. Paring and boiling of chestnuts were carried out by the use of four different methods as are microwave, oven, microwave-oven combination and autoclave, and four different $CaCl_2$ ratios as are 0 (control), 0.1, 0.2 and 0.3%. Three different sugar syrups; sucrose, glucose and sorbitol, were used in sugar-dipping of chestnuts. The results of candied chestnuts were ranged between 10.42-11.53 g for kernel weight and 32.88-34.00, 26.13-27.00 and 20.75-21.75 mm for width, length and thickness, respectively. It was found that the hardness was between 3.34-3.44 kg and the L^*, a^* and b^* values were between 39.35-46.04, 5.88-6.64 and 24.15-27.69, respectively. The moisture content, water activity, pH, titratable acidity and enzyme resistant starch content were determined between 25.72-27.08%, 0.82-0.88, 6.67-6.88, 0.04-0.05% and 1.20-1.56%, respectively. Candied chestnuts produced by the use of sorbitol were considered to be well sensory acceptable by panellists.

Keywords: chestnut, confectionary, diet, sugar alcohol, health

1. Introduction

The chestnut tree belongs to the *Castanea* genus in the *Fagaceae* family (Martín *et al.*, 2007). Its seeds are consumable as food (Neri *et al.*, 2010). Chestnut production is mainly concentrated in Asia, North America and Europe. *Castanea crenata* Sieb. et Zucc., *Castanea mollissima* Bl., *Castanea seguinii* Dode, *Castanea davidii* Dode and *Castanea henryi* Rehder and Wilson species are produced in Asia. *Castanea dentata* Borkh., *Castanea pumila* (L.) Mill., *Castanea floridana* (Sarg.) Ashe, *Castanea ashei* (Sudw.) Ashe, *Castanea alnifolia* Nutt. and *Castanea paucispina* Ashe species are grown in North America. Additionally, *Castanea sativa* Mill., known as sweet chestnut, is produced in Europe and used for the production of candy (De Vasconcelos *et al.*, 2007).

The global chestnut production was about 2.3 Mt in 2016 and the main producer of chestnuts is China, which produces approximately 1.9 Mt. Turkey ranks third in the world's chestnut production, producing 0.065 Mt (FAO, 2017).

Chestnut is a healthy and valuable food, due to its high energy content (Bounous and Marinoni, 2005). It is reported to the literature that chestnuts may contain 40-64% moisture and 50-60% starch, 20-30% sugar, 4-11% protein, 4-10% fibre, 2-8% mineral and 1-4% lipid on a dry basis, as well as vitamins, such as vitamin E and B groups (Aguilar *et al.*, 2016; De Vasconcelos *et al.*, 2010). Chestnuts are distinguished from other nuts by their high complex carbohydrates and low lipid contents, and thus they are suitable for diets (Bounous and Marinoni, 2005; Ertürk *et al.*, 2006).

Chestnut can be consumed in many different forms (Bounous and Marinoni, 2005; Neri *et al.*, 2010), such as fresh, boiled, roasted or flour (Zhu, 2016) and also, as confectionary, called candied chestnut (De Vasconcelos *et al.*, 2007; Sakin-Yilmazer *et al.*, 2014).

Candied chestnut is prepared by dipping the pared and boiled chestnuts in sugar syrup. Sucrose and glucose mixtures are usually used in its production, to avoid crystallisation in the final product at room temperature (Bounous and Marinoni, 2005). Other sugar sources, such as fructose, can also be used in the production of candied chestnut (Korel and Balaban, 2006) but there is no research about the use of sugar alcohols, such as sorbitol, as a sweetener and preservative.

Sugar alcohols are high added value ingredients. They are produced from carbohydrates through bio-refinery (Conceiçao *et al.*, 2012), and their digestibility is low. Consumers and diabetics can obtain less energy by consuming sugar alcohols because of their low calories and lack of insulin requirement for metabolism. Sorbitol is a sugar alcohol produced by hydrogenating glucose in the presence of a catalyst (Grembecka, 2015). Sorbitol can be used in confectionery products as a sugar substitute in dietary and diabetic food products (Vilela *et al.*, 2016).

Although previous studies have been done on raw and candied chestnut, there is no published research on candied chestnut produced using sugar alcohol. Furthermore, no prior publications have examined the changes that occur in all stages (paring, boiling and sugar-dipping) of candied chestnut production. Therefore, this study examined the changes taking place in all stages of candied chestnut production and the possibility of using sorbitol as a sugar substitute from a health perspective.

2. Materials and methods

Materials

Chestnuts and sugar were obtained from a local market in Antalya, Turkey, in 2016. Food grade sorbitol (ZAG Chemistry, Istanbul, Turkey), sugar syrup (Alfasol, Sao Paulo, Brasil), resistant starch assay kit (Megazyme Int. Wicklow, Ireland) and analytical grade chemicals (Merck, Darmstadt, Germany and Sigma, Taufkirchen, Germany) were used in the research. Physical analyses were conducted with the whole chestnut and chemical analyses were performed with milled chestnut, obtained by using a Waring blender (HGB2WTS3, Waring Laboratory, Torrington, CT, USA). All samples were stored in polyethylene plastic bags at -18 °C until analyses.

Paring of chestnuts

Firstly, the most suitable method for paring was identified to produce candied chestnut. For this purpose, the chestnuts were scratched annularly at their widest place, with a sharp knifepoint. Scratched chestnut samples were processed, by the use of four different applications including autoclave (105 °C, 15 min), microwave (180 W, 5 min), oven (180 °C, 15 min) and microwave-oven combination (180 °C, 180 W, 5 min). The different process conditions for paring were determined by preliminary tests. It was determined that the most suitable method for paring was the microwave process because chestnuts were pared easily and did not crumble.

Boiling of chestnuts

After the application of the microwave process, the pared chestnuts were boiled in 0.2% citric acid solution with four different $CaCl_2$ ratios (0, 0.1, 0.2 and 0.3%) for 20 min to prevent softening and crumbling. The control was prepared without $CaCl_2$ (0%). It was determined that the most suitable $CaCl_2$ ratio for boiling was 0.2% because the chestnuts did not crumble after boiling.

Sugar-dipping of chestnuts

After boiling of chestnuts with 0.2% citric acid and 0.2% $CaCl_2$, the chestnut samples were dipped in three different 55 °Bx sugar syrups (sucrose, glucose and sorbitol) for 60 h. Then, they were dipped in the same sugar syrups at 75 °Bx for 2.5 h, at room temperature. The candied chestnuts were removed from sugar syrups and the production process was completed.

Determination of physical properties of raw and processed chestnuts

Physical properties, such as number of chestnuts in 1 kg, kernel weight and 1000-kernel weight of crusted, pared, boiled and candied chestnut samples were determined by weighing chestnuts. The chestnut sample dimensions were measured with a calliper. Hardness and fracturability of the chestnut samples were determined by using a texture analyser device (TA.XTplus, Stable Micro Systems, Surrey, UK), equipped with an SMSP/10 cylinder probe for crusted and pared chestnut samples, and an SMS5 cylinder probe (35 mm) for boiled and candied chestnut samples. Colour parameters (L^*, a^* and b^*) of the chestnut samples were measured according to the CIELAB system by using a CR-400 chromameter (Konica Minolta, Japan) (Erbas, 2010). According to the CIELAB system, L^*, a^* and b^* values represent blackness and whiteness, greenness and redness, and blueness and yellowness, respectively (Mapari *et al.*, 2006).

Determination of moisture content and water activity

The moisture content was determined by drying 2 g of sample in an oven (UNB 500, Memmert GmbH + Co. KG, Schwabach, Germany) at 105 °C for crusted, pared and boiled chestnut samples, and 70 °C for candied chestnut samples, until reaching a constant weight. Water activities of the chestnut samples were measured by using an Aqua Lab 4TE (Decagon Devices, Inc., Pullman, WA, USA) analyser device.

Determination of enzyme resistant and total starch contents

For pH determination, 2 g of samples were homogenised in 18 mL distilled water at ambient temperature for 1 min, with an Ultra-Turrax T-25 (IKA Labortechnik, Staufen, Germany) and filtered through Whatman no. 42 filter paper. The pH values of the obtained homogenates were determined with a digital pH meter (WTW 537, Weilheim, Germany).

The titratable acidities of all chestnut samples were determined according to the potentiometric method. For this purpose, homogenates obtained from pH analysis were titrated with 0.1 N of NaOH, until reaching pH 8.1, while mixing continuously with a magnetic stirrer (Bhat *et al.*, 2011). The results were expressed as citric acid percentage on a wet basis (Peña-Méndez *et al.*, 2008).

Determination of enzyme resistant starch and total starch content

Enzyme resistant starch (ERS) and total starch analyses were performed using a resistant starch assay kit (Megazyme Int. Wicklow, Ireland), according to the standard method (AACC, 2010a,b), with some modifications. The total starch consists of non-resistant starch and ERS.

For analysis, 0.1 g of sample was weighed into a tube and 4 ml of pancreatic α-amylase solution (10 mg/ml) containing amyloglucosidase (AMG) (3 U/ml) was added. The mixture was incubated for 16 h at 37 °C in a horizontal shaking water bath with a speed of 100 rpm. During this incubation period, the non-resistant starch converted into glucose. Next, the enzyme reaction was terminated by the addition of 4 ml of 99% ethyl alcohol solution and the obtained mixture was centrifuged at 4,500×*g* for 5 min. The pellet and supernatant were separated and the supernatant was transferred to an empty tube. The remaining pellet was re-suspended in 50% ethyl alcohol solution, followed by centrifugation at 4,500×*g* for 5 min, to separate the supernatant and pellet. This step was repeated once more and the separated supernatants were transferred to an empty tube. At the end of this period, the excess water of the obtained pellet was removed by vacuum incubation at 40 °C.

For determining the non-resistant starch content, the supernatants separated by centrifugation were combined and this mixture was adjusted to 100 ml of sodium acetate buffer (100 mM, pH 4.5) in a volumetric flask. 0.1 ml of this mixture was placed in a glass tube then 10 µl of diluted AMG solution (300 U/ml) was added and the mixture was incubated at 50 °C for 20 min. Then, 3 ml of glucose oxidase/peroxidase (GOPOD) reagent was added to the tube and this tube was incubated with a blank sample and a standard glucose solution, at 50 °C for 20 min. For preparing the blank and D-glucose standard solution, 3 ml of GOPOD reagent was added to 0.1 ml of sodium acetate buffer (100 mM, pH 4.5) and 0.1 ml of D-glucose standard, respectively. After the incubation period, the absorbance of the sample and the D-glucose standard were measured against the blank sample at 510 nm in a spectrophotometer (UV-1800, Shimadzu, Japan). The non-resistant starch content of the samples was calculated by the following equation:

$$\% \text{ Non-resistant starch content} = \Delta E \times (F/W) \times 90$$

where ΔE, F and W represent the absorbance of the sample, conversion from absorbance to micrograms and the dry weight of the sample, respectively.

For determining resistant starch, 2 ml of potassium hydroxide (2 M) was added to the obtained pellet and the mixture was stirred with a magnetic stirrer in an ice bath for 20 min. Next, 8 ml of sodium acetate buffer (1.2 M, pH 3.8) and 0.1 ml of AMG (3,300 U/ml) were added to the pellet. The mixture was stirred, incubated at 50 °C for 30 min and then centrifuged at 4,500×*g* for 5 min. Afterwards, 0.1 ml of the supernatant was mixed with 3 ml GOPOD reagent in a glass tube. This sample solution was incubated at 50 °C for 20 min, alongside the D-glucose standard and blank sample, was prepared as described above. Finally, the absorbance of the sample was measured against the blank sample at 510 nm. The ERS content of the samples was calculated by the following equation:

$$\% \text{ ERS content} = \Delta E \times (F/W) \times 9.27$$

where ΔE, F and W represent the absorbance of the sample, conversion from absorbance to micrograms and the dry weight of the sample, respectively.

The total starch content of the chestnut samples was calculated by summing the amounts of non-resistant starch and ERS.

Determination of sensorial properties of candied chestnut samples

Sensory analysis was performed on candied chestnut produced with syrups of sucrose, glucose and sorbitol. The selected parameters were colour, appearance, texture,

bitterness, sourness, sweetness, metallic taste, odour and overall parameters. Sensory evaluation was performed by 10 trained postgraduate students, using a 5-point hedonic scale (1: very bad; 5: very good).

Statistical analysis

While the physical analyses of crusted chestnuts were made with twenty chestnut samples, the chemical analyses of them were made with four samples. The results were given by calculating the standard error of these measurements. Four different paring methods, four different $CaCl_2$ ratios and three different sugar syrups were used in the paring, boiling and sugar-dipping stages of candied chestnut production, respectively. The physical and chemical analyses of pared, boiled and candied chestnut samples were conducted on four parallel for each stage, and research was made with two replicates. All statistical analyses were performed using SAS Statistical software (SAS Institute Inc., Cary, NC, USA). Significance was evaluated by analysis of variance (ANOVA), followed by Duncan's multiple range test ($P<0.05$). Results were presented as mean ± standard error.

3. Results and discussion

Physical and chemical properties of crusted chestnut

The physical and chemical properties of crusted chestnut are given in Table 1. Chestnuts are classified according to number of chestnuts in 1 kg, into four different groups, which include *AAA* (fewer than 48/kg), *AA* (48-65/kg), *A* (66-85/kg) and *B* (more than 85/kg) (Bounous and Marinoni, 2005). According to the results, the chestnut samples used in this research were classified as group *A*. The number of chestnuts in 1 kg indicates the size of chestnuts and it varies according to the growing conditions. A previous study reported that the number of chestnuts produced in Turkey ranged from 51-78/kg (Ertan and Kılınç, 2005).

The kernel weight and 1000-kernel weight of crusted chestnut samples were determined as 12.37 g and 12.99 kg, respectively. It was reported that chestnut kernel weight can vary between 5.00-21.40 g, depending on the region (Ertan and Kılınç, 2005). In a study carried out by Antonio *et al.* (2013), the kernel weight of various chestnut varieties ranged between 12.17-18.94 g.

The width, length and thickness of crusted chestnuts were determined as 36.22, 31.30 and 22.00 mm, respectively. In a study conducted with four different chestnut species, the width, length and thickness of chestnut samples ranged between 31.36-36.84, 35.82-36.77 and 18.41-25.95 mm, respectively (Antonio *et al.*, 2013). From an industrial point of view, small chestnuts (width<30 mm) are generally used in bakery, while medium and large chestnuts are consumed fresh or in confectionery form (Silva *et al.*, 2011). Therefore, the used chestnuts were suitable for candied chestnut production because the width of the chestnuts was higher than 30 mm.

Table 1. Some physical and chemical properties of crusted chestnut.[1]

Physical properties, n=20	Values
The number of chestnuts in 1 kg	75.50±2.40
Kernel weight (g)	12.37±0.46
1000-kernel weight (kg)	12.99±0.19
Dimensions (mm)	
Width	36.22±0.46
Length	31.30±0.35
Thickness	22.00±0.44
Hardness (kg)	37.49±2.79
Fracturability (kg)	32.94±3.09
Colour	
*L**	31.06±0.49
*a**	8.11±0.39
*b**	12.78±0.69
Chemical properties, n=4	
Moisture content (%)	47.56±0.54
Water activity	0.97±0.00
pH	6.63±0.02
Titratable acidity (%)	0.16±0.01
ERS content (%)	21.89±0.23
Total starch content (%)	52.24±2.67

[1] ERS = enzyme resistant starch.

Texture properties, such as hardness and fracturability, are indicative of the foods' rheological properties, in terms of robustness (Silva *et al.*, 2011). The hardness and fracturability of the crusted chestnuts were determined as 37.49 and 32.94 kg, respectively.

Based on the obtained L^*, a^* and b^* colour values, the crusted chestnuts can be described as dark brown. Antonio *et al.* (2013) reported that the L^* and b^* values of chestnuts varied between 30-35 and 10-18, respectively.

Chestnut has a high moisture content and water activity (Peña-Méndez *et al.*, 2008; Sakin-Yilmazer *et al.*, 2014; Zhu, 2016). In the current study, these values were determined as 47.56% and 0.97, respectively. In some previous studies, the moisture content of raw chestnuts was found to be between 42.27-52.89% (Neri *et al.*, 2010) and 53.06-57.20% (Peña-Méndez *et al.*, 2008).

The pH and titratable acidity of crusted chestnuts were found as 6.63 and 0.16%, respectively. In a study, it was reported that the pH value of chestnut is about 7.00 (Gong *et al.*, 2015).

The ERS and total starch content of crusted chestnut samples were detected as 21.89 and 52.24%, on a dry basis. Given that the starch content of chestnut is 52.24%, this ERS amount corresponds to more than 40% of crusted chestnut starch. In some studies, it was reported that the starch content of chestnut was 50-60% on a dry basis (Aguilar *et al.*, 2016; De Vasconcelos *et al.*, 2010). In another research, the ERS content had been determined as 57.56% in raw chestnut starch (Pizzoferrato *et al.*, 1999). Correia and Beirão-da-Costa (2012) reported that the ERS content of raw chestnut flour varied between 28.90-36.00%, depending on the chestnut species.

Physical and chemical properties of pared chestnut

Some physical and chemical properties of the pared chestnuts treated by different methods are given in Table 2. It was determined that the kernel weight of pared chestnuts was significantly (P<0.05) affected by the paring methods. The kernel weight of chestnut samples pared by the autoclave process was significantly (P<0.05) higher than that of the samples pared by the other processes. The paring methods caused moisture loss during treatment with the exception of the autoclave process. Due to the use of humid hot air in this process, the samples became damp, causing an increase in weight.

According to the paring methods, there was no significant (P>0.05) difference in the pared chestnut dimensions, except for length (P<0.05). The highest dimensions were measured in pared samples prepared by the microwave process. Because the volume of water inside the sample increased by heat treatment during the microwave process. Volume change occurs due to the moisture loss and gain, which causes gas or pore formation during the roasting or boiling of foods (Silva *et al.*, 2011).

High hardness is key for pared chestnut because it is necessary to retain the whole chestnut throughout the progressive stages of candied chestnut production. The hardness of chestnuts was significantly (P<0.01) affected by the paring methods. For the chestnuts pared using the oven method, the hardness could not be measured, due to the excessive crumbling.

A light colour is crucial in the production of candied chestnut. It was determined that there was no statistically significant (P>0.05) difference in colour values, except for the a^* values (P<0.05). The a^* values of the chestnuts processed by microwave were lower than those of the chestnuts treated by the other methods. The lighter colour may have occurred in chestnuts pared by the microwave process, due to the less browning. The small increase in

Table 2. Some physical and chemical properties of chestnuts pared by different methods.[1]

Properties	Paring methods, n=2				
	Microwave	Oven	Combination (M-O)	Autoclave	Significance
Kernel weight (g)	9.47^{b}±0.12	9.49^{b}±0.25	9.31^{b}±0.11	10.77^{a}±0.15	*
Dimensions (mm)					
Width	33.75^{a}±4.00	30.75^{a}±0.75	31.38^{a}±3.38	31.88^{a}±2.38	–
Length	30.50^{a}±1.00	24.25^{b}±0.25	25.38^{ab}±2.38	26.63^{ab}±0.63	*
Thickness	20.26^{a}±0.13	19.88^{a}±0.25	19.51^{a}±0.38	20.19^{a}±0.06	–
Hardness (kg)	12.86^{a}±0.08	nd	13.33^{a}±0.55	5.41^{b}±0.75	**
Colour					
L^*	69.38^{a}±1.10	59.99^{a}±3.13	65.04^{a}±0.49	58.01^{a}±5.52	–
a^*	-2.03^{b}±0.41	2.79^{a}±1.19	-0.50^{ab}±1.87	2.35^{ab}±0.26	*
b^*	38.53^{a}±0.23	39.86^{a}±1.44	39.81^{a}±1.70	32.84^{a}±4.25	–
Moisture content (%)	43.47^{ab}±2.04	38.79^{b}±0.03	40.77^{b}±2.03	47.98^{a}±0.02	*
Water activity	0.98^{a}±0.00	0.96^{b}±0.00	0.97^{b}±0.01	0.97^{b}±0.01	*
pH	6.49^{a}±0.02	6.49^{a}±0.14	6.56^{a}±0.05	6.43^{a}±0.06	–
Titratable acidity (%)	0.11^{a}±0.00	0.11^{a}±0.01	0.09^{a}±0.01	0.12^{a}±0.02	–
ERS content (%)	3.26^{a}±0.20	2.87^{a}±0.38	3.46^{a}±0.16	3.27^{a}±0.05	–

[1] Different superscript letters in the same row denote that the samples are significantly different by Duncan's multiple range test; ** and * represent significance level at P≤0.01 and 0.01<P≤0.05, respectively; ERS = enzyme resistant starch; M-O = microwave-oven; nd = not detected.

the a^* value by the microwave process indicates that the products obtained by this method are less brown than the products produced using conventional methods (Vadivambal and Jayas, 2007). Namely, it is quite easy to achieve a light colour in food products prepared by microwave cooking. The colour formed as a result of the Maillard reaction affects the commercial value of foods that are cooked by the use of the microwave (Ibrahim *et al.*, 2012). Korel and Balaban (2006) reported that the L^*, a^* and b^* values of pared raw chestnuts obtained from the market were approximately 45.00, 11.00 and 39.00, respectively.

The moisture content and water activity of the chestnuts were significantly (P<0.05) affected by the paring methods. While the lowest moisture content and water activity values were determined in chestnuts processed in the oven, because of vaporisation, the highest values were detected for the autoclave and microwave treatments, respectively. It is thought that the moisture contents of the chestnuts were different due to the short processing time in the microwave and combination processes and the use of vapour in the autoclave. Bounous and Marinoni (2005) reported that the moisture content of chestnut decreased from 52.90 to 42.40% after roasting of fresh chestnut.

The pH value and titratable acidity of the pared chestnuts were not significantly (P>0.05) affected by the paring methods. The composition of chestnut changes depending on the variety, harvesting time and soil conditions (Yang *et al.*, 2015). Peña-Méndez *et al.* (2008) reported that the pH value and the total acidity of 105 commercial chestnut samples were between 7.04-7.08 and 0.02-0.08%, respectively.

The ERS content of pared chestnuts was not significantly (P>0.05) affected by the paring methods. The ERS content of pared chestnuts was found to be between 2.87-3.46% (approximately 5.49-6.62 g ERS/100 g starch). Chestnut starch is a type II ERS (Correia *et al.*, 2012) and the amount of type II ERS decreases with food processing and cooking (Nugent, 2005). Pizzoferrato *et al.* (1999) reported that the ERS content of raw chestnut starch decreased from 57.56 to 16.91 g/100 g after roasting. In both the current study and the literature data, it was determined that a large part of the ERS content of chestnut passes to the soluble form after thermal processing.

Paring is one of the most important steps in candied chestnut processing. The separation of the outer and inner shells is a challenging and laborious process (Yang *et al.*, 2015). The microwave application was the best paring method in current study. Because the outer and inner shells of chestnut were separated easily from the fruit flesh in a short time (5 min) and the original properties of chestnuts were retained. Therefore, the pared samples treated by the microwave process were selected for the boiling step in candied chestnut production.

Physical and chemical properties of boiled chestnut

Some physical and chemical properties of chestnuts boiled in citric acid (0.2%) and water with the addition of different amounts of $CaCl_2$ (0, 0.1, 0.2 and 0.3%) are given in Table 3. There was no significant (P>0.05) difference regarding the chestnut kernel weight. The kernel weight of boiled chestnuts with different percentages of $CaCl_2$ was determined to be between 9.97-11.19 g.

There was no significant (P>0.05) difference in the dimensions of boiled chestnuts, except for length (P<0.05). These differences may arise from moisture diffusion into the chestnut during boiling.

The boiling process leads to undesirable changes in the quality characteristics of pared chestnut, particularly texture. The hardness of the samples was significantly (P<0.05) affected by the different boiling solutions. After the boiling process, the hardness of the chestnuts boiled with solutions containing different percentages of $CaCl_2$ ranged between 3.58-3.85 kg. Calcium salts form calcium pectate, as a result of binding to pectic substances, which makes foods more resistant to thermal softening (Del Valle *et al.*, 1998; Perez-Aleman *et al.*, 2005). Due to this effect of $CaCl_2$, it is considered that the hardness value of the chestnut samples was higher in the 0.2 and 0.3% $CaCl_2$ solutions than in the others. As a result of the descriptive evaluation, it was determined that the highest hardness was measured in the samples boiled with 0.2% $CaCl_2$.

There was no significant (P>0.05) difference between samples in terms of L^* and a^* values, but the b^* values were significantly (P<0.05) affected by boiling with $CaCl_2$. The lowest b^* value was determined in the sample boiled with 0.3% $CaCl_2$.

The moisture content and the water activity of boiled chestnuts were significantly (P<0.01) affected by the different boiling treatments. The lowest moisture content and water activity were recorded in chestnuts boiled with 0.1 and 0.2% $CaCl_2$, respectively. Bounous and Marinoni (2005) reported that boiling increased the moisture content of chestnuts from 52.90 to 63.30%.

The pH values were significantly (P<0.01) affected by the different boiling treatments, but the titratable acidity values were not significantly affected (P>0.05). From 0.1% $CaCl_2$ onwards, the pH value of the samples decreased with the increment in the $CaCl_2$ percentage. Accordingly, the titratable acidity values moved in the opposite direction. Some studies in the literature have reported that calcium has a pH lowering effect (Chen *et al.*, 2016; Levine and Ryan, 2009). Therefore, it was thought that the pH and titratable acidity values changed because of the $CaCl_2$ content increase.

Table 3. Some physical and chemical properties of chestnuts boiled with different ratio of $CaCl_2$ solution.[1]

Properties	$CaCl_2$ ratio, n=2				
	0% $CaCl_2$	0.1% $CaCl_2$	0.2% $CaCl_2$	0.3% $CaCl_2$	Significance
Kernel weight (g)	11.19^{a}±0.04	10.58^{a}±0.45	9.97^{a}±0.77	10.90^{a}±0.32	–
Dimensions (mm)					
Width	34.75^{a}±1.75	34.50^{a}±1.00	33.75^{a}±0.25	34.63^{a}±1.63	–
Length	27.38^{ab}±0.38	26.75^{bc}±0.25	25.75^{c}±0.25	28.00^{a}±0.25	*
Thickness	21.00^{a}±1.00	19.00^{a}±1.50	18.25^{a}±2.25	19.63^{a}±0.13	–
Hardness (kg)	3.68^{ab}±0.08	3.58^{b}±0.05	3.85^{a}±0.05	3.82^{a}±0.06	*
Colour					
*L**	52.15^{a}±3.65	52.89^{a}±0.81	50.92^{a}±0.82	52.76^{a}±1.43	–
*a**	3.16^{a}±2.09	3.38^{a}±1.89	4.34^{a}±0.47	1.43^{a}±0.82	–
*b**	31.70^{a}±0.85	30.63^{a}±0.33	33.31^{a}±0.80	23.44^{b}±2.48	*
Moisture content (%)	60.09^{a}±0.37	56.87^{c}±0.22	58.41^{b}±0.42	58.96^{ab}±0.19	**
Water activity	0.97^{b}±0.00	0.97^{b}±0.00	0.96^{c}±0.00	0.99^{a}±0.00	**
pH	5.79^{b}±0.01	5.95^{a}±0.03	5.94^{a}±0.01	5.80^{b}±0.01	**
Titratable acidity (%)	0.13^{a}±0.00	0.12^{a}±0.01	0.13^{a}±0.01	0.13^{a}±0.01	–
ERS content (%)	3.33^{a}±0.31	2.86^{a}±0.01	3.48^{a}±0.42	3.10^{a}±0.01	–

[1] Different superscript letters in the same row denote that the samples are significantly different by Duncan's multiple range test; ** and * represent significance level at $P \leq 0.01$ and $0.01 < P \leq 0.05$, respectively; ERS = enzyme resistant starch.

There were no statistically significant ($P>0.05$) differences among the samples regarding ERS content and it was found to be between 2.86-3.48%. The ERS content of boiled chestnut was almost the same as that of pared chestnut. Therefore, it was thought that a large part of the type II ERS content of chestnuts had passed to the soluble form in the paring phase.

As a result, the most favourable chestnut was obtained by boiling with 0.2% $CaCl_2$ in terms of the structural integrity of the boiled chestnuts. Under these conditions, the number of whole pared chestnuts that were not broken into small pieces was higher (60%) than that in the other solutions used for boiling. Additionally, their appearance and colour were the best after boiling. Therefore, the production of candied chestnut continued with the sample of being boiled with 0.2% $CaCl_2$.

Physical and chemical properties of candied chestnut

Some physical and chemical properties of candied chestnuts produced by using three different sugar sources (sucrose, glucose and sorbitol) are given in Table 4. There were no significant ($P>0.05$) differences in kernel weight among the samples. This result might be expected because the syrups prepared by using sucrose, glucose and sorbitol were adjusted to the same Brix value.

There were no significant ($P>0.05$) differences in the dimensions among the candied chestnut samples regarding the sugar source. The width, length and thickness of the candied chestnuts were measured as 32.88-34.00, 26.13-27.00 and 20.75-21.75 mm, respectively.

Texture properties of candied chestnuts affect consumers' purchasing preference. The candied chestnut should have reasonable hardness for easy chewing (Korel and Balaban, 2006). There was no significant ($P>0.05$) difference in hardness among the samples, which varied between 3.34-3.44 kg.

Colour is one of the parameters that affects the purchasing preferences of consumers (Antonio *et al.*, 2013), and the colour of candied chestnut should be light brown (Korel and Balaban, 2006). There were no significant ($P>0.05$) colour differences among the candied chestnuts.

Although the moisture content was not significantly ($P>0.05$) different among the samples, the water activity was significantly ($P<0.05$) affected by the sugar sources. Water activity was the lowest in samples containing sorbitol. Such a result may be attributed to the extra hydroxyl groups that sorbitol contains, resulting in binding more water molecules compared to glucose. Vilela *et al.* (2016) reported that the water activity of some candied fruits produced by using sorbitol varied between 0.80-0.82. In another study, the

Table 4. Some physical and chemical properties of candied chestnuts produced with different sugar syrups.[1]

Properties	Sugar source, n=2			
	Sucrose	Glucose	Sorbitol	Significance
Kernel weight (g)	11.53^{a}±0.02	11.15^{a}±0.07	10.42^{a}±0.79	–
Dimensions (mm)				
Width	32.88^{a}±0.50	33.38^{a}±0.63	34.00^{a}±0.25	–
Length	26.88^{a}±0.63	26.13^{a}±0.88	27.00^{a}±0.00	–
Thickness	21.50^{a}±0.00	21.75^{a}±0.75	20.75^{a}±0.25	–
Hardness (kg)	3.43^{a}±0.00	3.44^{a}±0.21	3.34^{a}±0.00	–
Colour				
*L**	41.20^{a}±2.53	39.35^{a}±0.94	46.04^{a}±3.31	–
*a**	6.32^{a}±0.52	6.64^{a}±0.36	5.88^{a}±0.56	–
*b**	24.89^{a}±1.69	24.15^{a}±1.13	27.69^{a}±2.32	–
Moisture content (%)	27.08^{a}±1.32	25.72^{a}±2.1	25.91^{a}±1.54	–
Water activity	0.88^{a}±0.01	0.86^{ab}±0.02	0.82^{b}±0.01	*
pH	6.88^{a}±0.18	6.67^{a}±0.11	6.85^{a}±0.18	–
Titratable acidity (%)	0.05$^{a\pm}$0.01	0.05^{a}±0.01	0.04^{a}±0.00	–
ERS content (%)	1.20^{a}±0.13	1.56^{a}±0.04	1.42^{a}±0.12	–

[1] Different superscript letters in the same row denote that the samples are significantly different by Duncan's multiple range test; * represent significance at level $0.01<P\leq0.05$; ERS = enzyme resistant starch.

moisture content of pared raw chestnut was determined as 55.09%, but at the end of the candied chestnut production process, moisture content decreased to 23.69%. During candied chestnut production, sugar is diffused into the chestnut and the moisture content is reduced because the sugar replaces the water inside the chestnut (Korel and Balaban, 2006).

There was no significant ($P>0.05$) difference in pH and titratable acidity among the samples, which ranged between 6.67-6.88 and 0.04-0.05%, respectively.

No significant ($P>0.05$) difference in the ERS content of the samples produced by using different sugar sources was evident. The ERS content of candied chestnut varied between 1.20-1.56%. It was thought that the obtained result was lower than the ERS content of boiled chestnut because a significant portion of the candied chestnut is formed from sugar. Therefore, the retrogradation of starch was suppressed due to the high sugar concentration and the ERS content did not increase.

Sensorial properties of candied chestnut

The sensorial properties of candied chestnut are given in Table 5. The colour, appearance and odour parameters were significantly ($P<0.05$; $P<0.01$) affected by the sugar sources. The sensory scores of candied chestnuts produced by using sorbitol were descriptively lower than those of the others. However, produced candied chestnuts were considered as sensory acceptable because the parameters received more than 3 points, the middle value of the 5-point hedonic scale.

4. Conclusions

In conclusion, although candied chestnut production has been traditionally sustained in the world for many years, studies on this product are limited. The use of alternative sugar sources instead of sucrose is not very common in candied chestnut production. Thus, it is considered that the current study may help in the future studies of candied chestnuts. Additionally, the production of sweet foods by using low-calorie materials, such as sugar alcohols, is preferred by consumers because of health concerns. Therefore, it is considered that producing candied chestnut as a low-calorie and diabetic food by using sorbitol, may positively affect the purchasing preferences of consumers.

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Table 5. Sensorial properties of candied chestnut.[1]

Properties	Sugar source, n=2			
	Sucrose	Glucose	Sorbitol	Significance
Colour	4.38^{a}±0.13	4.26^{a}±0.13	3.75^{b}±0.00	*
Appearance	4.38^{a}±0.13	4.13^{ab}±0.00	3.88^{b}±0.00	*
Texture	3.69^{a}±0.19	3.57^{a}±0.07	3.25^{a}±0.00	–
Bitterness	4.44^{a}±0.19	4.19^{a}±0.19	3.75^{a}±0.00	–
Sourness	4.57^{a}±0.32	4.44^{a}±0.44	3.63^{a}±0.00	–
Sweetness	4.25^{a}±0.00	4.07^{a}±0.32	4.38^{a}±0.00	–
Metallic taste	4.63^{a}±0.25	4.57^{a}±0.07	4.13^{a}±0.00	–
Odour	4.38^{a}±0.13	4.25^{a}±0.00	3.25^{b}±0.00	**
Overall	4.19^{a}±0.19	4.01^{a}±0.13	3.63^{a}±0.00	–

[1] Different superscript letters in the same row denote that the samples are significantly different by Duncan's multiple range test; ** and * represent significance level at $P \leq 0.01$ and $0.01 < P \leq 0.05$, respectively.

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